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A STUDY OF PROCESS COSTS AND ECONOMICS OF PYRITE-COAL UTILIZATION

a report to

PROCESS CONTROL ENGINEERING PROGRAM

**CONSUMER PROTECTION AND
ENVIRONMENTAL HEALTH SERVICE**

**U. S. DEPARTMENT OF HEALTH,
EDUCATION AND WELFARE**

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Arthur D. Little, Inc.

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by

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March 1968

Arthur D. Little, Inc.

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TABLE OF CONTENTS

Page

List of Tables v

List of Figures xi

I. INTRODUCTION I-1

A. BACKGROUND I-1

B. OBJECTIVE I-3

C. APPROACH I-4

D. ACKNOWLEDGEMENTS I-6

II. SUMMARY II-1

A. PROCESS ECONOMICS II-1

B. SULFURIC ACID MARKET II-14

C. INTEGRATED PYRITE-BASED FERTILIZER MANUFACTURING OPERATION, CAIRO, ILLINOIS II-20

D. SUMMARY OF ESTIMATED INCOME PER TON OF LOW-SULFUR COAL RESULTING FROM PYRITE BENEFICIATION AND UTILIZATION II-22

III. PROCESS ECONOMICS III-1

A. ECONOMICS OF BENEFICIATION PROCESSES III-1

B. MANUFACTURE OF SULFURIC ACID FROM PYRITE III-28

C. CALCINE UTILIZATION III-100

IV. SULFURIC ACID MARKET IV-1

A. UNITED STATES IV-1

B. SPECIFIC MARKETING AREAS CONSIDERED IV-14

TABLE OF CONTENTS (Continued)

Page

IV. SULFURIC ACID MARKET (continued)

C. MAJOR USES OF SULFURIC ACID-TECHNICAL CONSIDERATIONS IV-17

D. SULFURIC ACID CONSUMPTION IN POTENTIAL PRODUCING AREAS IV-39

V. INTEGRATION OF ALL FACTORS IN PRICE VALUATION OF PYRITES FOR SUPPLYING SULFURIC ACID AND STEAM TO A LARGE PHOSPHATE FERTILIZER PROJECT V-1

A. PROCESS DESCRIPTION FOR PHOSPHATE FERTILIZER MANUFACTURING V-1

B. REGIONAL PHOSPHATE DEMAND-SUPPLY OUTLOOK IN THE UNITED STATES V-2

C. PHOSPHATE-TRADE ROUTE PATTERNS TO SERVE UPPER MIDWEST MARKETS V-8

D. PLANT LOCATION CONSIDERATIONS FOR A PHOSPHATE PLANT BASED UPON SULFURIC ACID FROM PYRITES V-8

E. CONSIDERATION OF THE VALUE OF PYRITE FOR PYRITE MANUFACTURING IN ORDER FOR SULFUR FROM PYRITE TO BE COMPETITIVE WITH SULFUR FROM BRIMSTONE V-13

APPENDIX A A-1

APPENDIX B B-1

LIST OF TABLES

Table No.		Page
II-1	Summary of Advantages and Disadvantages to Utilities and Mines in Using Low-sulfur Coal	II-4
II-2	Total Processing Costs (Dollars per ton of 98% Product Acid) vs Pyrite Plant Feed Composition and Plant Capacity	II-10
II-3	Battery Limit Costs and Total Investment versus Capacity and Feed Composition	II-11
II-4	Sulfuric Acid Distribution by End-Use	II-15
II-5	Summary of Estimated f.o.b. Prices for Pyrite Payable at Cairo, Illinois in a Competitive Situation	II-21
II-6	Estimated Income to Offset Beneficiation Costs Associated with Production of Low-Sulfur Coal and an Acceptable Pyrite Feed Material	II-23
III-1	Amount of Coal to be Processed to Yield Low-Sulfur Coal	III-5
III-2	Summary of Tangible Advantages and Disadvantages to Utilities in Using Low-Sulfur Coal	III-15
III-3	The Price that Can be Paid for Pyrites to Yield the Same Sulfuric Acid Manufacturing Cost as When Using Brimstone at $35 per Long Ton	III-23
III-4	The Price that Can be Paid for Pyrites to Yield the Same Sulfuric Acid Manufacturing Cost as When Using Brimstone at $40 per Long Ton	III-24
III-5	The Price that Can be Paid for Pyrites to Yield the Same Sulfuric Acid Manufacturing Cost as When Using Brimstone at $45 per Long Ton	III-25
III-6	Effect of Plant Capacity on Capital Investment Costs	III-31
III-7	Effect of Plant Feed Composition on Capital Investment Costs	III-32

LIST OF TABLES (Continued)

Table No.		Page
III-8	Processing Costs for Various Plant Capacities	III-34
III-9	Effect of Feed Composition on Processing Costs	III-35
III-10	Possible Low-Pressure Steam Credits	III-40
III-11	Plant Feed Composition Number	III-50
III-12	Pyrite Roasting Process Data - Plant Feed Composition Number	III-51
III-13	Sulfur Distribution and Recovery	III-54
III-14	Gas Scrubbing and Cooling Process Data - Plant Feed Composition Number	III-57
III-15	Calcine Characteristics and Amount - Pyrite Plant Feed Composition Number	III-58
III-16	Effect of Gangue on Process Requirements	III-60
III-17	Process Factors vs Pyrite Plant Feed Composition	III-62
III-18	Fluid-Bed Reactor Diameter/Capacity Relationships	III-66
III-19	Contact Acid Plant Water Balance Process Data	III-69
III-20	Analysis of Gas to Converter	III-71
III-21	Battery Limit Costs and Total Investment versus Capacity and Feed Composition	III-77
III-22	Total Land Requirements	III-80
III-23	Power Requirements	III-83
III-24	Power Cost versus Pyrite Plant Feed Consumption	III-84
III-25	Water Requirements for Pyrite Feed No. 2 and all Capacities	III-85

LIST OF TABLES (Continued)

Table No.		Page
III-26	Water Costs versus Pyrite Plant Feed Composition	III-86
III-27	Maintenance Materials and Supplies for Contact Acid Plant Section	III-87
III-28	Cost of Maintenance Materials and Supplies vs Plant Capacity and Pyrite Plant Feed Composition	III-89
III-29	Number of Roaster Lines and Contact Acid Lines vs Plant Capacity and Pyrite Plant Feed Composition	III-90
III-30	Operating Labor and Maintenance Labor Requirements for Pyrite Plant Feed Composition Number 2	III-91
III-31	Direct Operating and Maintenance Labor Cost vs Pyrite Plant Feed Composition and Plant Capacity	III-94
III-32	Total Direct Operating Costs (Dollars per ton 98% Acid)	III-95
III-33	Basis of Indirect Operating Costs	III-96
III-34	Total Indirect Operating Costs ve Pyrite Plant Feed Composition and Plant Capacity	III-97
III-35	Total Processing Costs (Dollars per ton of 98% Product Acid) vs Pyrite Plant Feed Composition and Plant Capacity	III-98
III-36	Amount and Approximate Analyses of Calcines	III-101
III-37	Analyses of Coal Brass Samples	III-104
III-38	Possible Calcine Values or Credits	III-106
III-39	Capital Investment and Operating Costs for Calcine Beneficiation	III-109
III-40	Recovered Iron	III-110
III-41	Analyses of Great Lakes Area Pellets	III-110

LIST OF TABLES (Continued)

Table No.		Page
IV-1	Estimated Regional Production and Disposition of Sulfuric Acid, 1966	IV-3
IV-2	Sulfuric Acid Distribution by End Use	IV-5
IV-3	Growth in Major Sulfuric Acid End Uses, United States	IV-7
IV-4	Sulfuric Acid Values	IV-9
IV-5	Estimated Sulfuric Acid End-Use Pattern in Selected States, 1966	IV-16
IV-6	Sulfuric Acid Supply-Demand Situation in Selected States, 1966	IV-18
IV-7	Summary of H_2SO_4 Usage for Pickling of Carbon Steel in Selected States	IV-21
IV-8	Major Steel Mills and Estimated Sulfuric Acid Demand	IV-24
IV-9	Refineries Using Sulfuric Acid for Alkylation	IV-28
IV-10	Major Producers of Sulfonated Detergents	IV-31
IV-11	Major Producers of Byproduct Ammonium Sulfate	IV-33
IV-12	Producers and Estimated Capacities of Rayon and Cellulosic Fibers	IV-36
IV-13	Major Sulfuric Acid Consumers and Estimated Demand in Pittsburgh Area, 1967	IV-40
IV-14	Analysis of Supply-Demand in Pittsburgh Area, 1967	IV-45
IV-15	Major Sulfuric Acid Consumers and Estimated Demand in Cairo-Paducah Area, 1967	IV-48
IV-16	Major Sulfuric Acid Consumers and Estimated Demand in St. Louis Area, 1967	IV-51

LIST OF TABLES (Continued)

Table No.		Page
IV-17	Major Sulfuric Acid Consumers and Estimated Demand in Chicago Area, 1967	IV-55
IV-18	Summary of Estimated Sulfuric Acid Demand in Potential Producing Areas, 1966	IV-62
IV-19	Sulfuric Acid Producers and Estimated Capacities in Competitive Areas	IV-63
IV-20	Projected Sulfuric Acid Consumption by Major End Use in Potential Producing Areas	IV-68
IV-21	Sulfuric Acid Supply and Estimated Demand in Potential Producing Areas	IV-70
V-1	U.S. Phosphate Fertilizer Consumption	V-3
V-2	Alternative Delivered Costs of Pyrite-Based Sulfuric Acid and Steam for Phosphate Fertilizer Manufacture at Cairo, Illinois	V-16
V-3	Manufacturing Cost for Sulfuric Acid from Brimstone at Cairo, Illinois and Baton Rouge, Louisiana	V-20
V-4	Approximate Value of Pyrite Delivered to Cairo Phosphate Complex Considering Alternative Locations for Phosphate Manufacturing and Brimstone as an Alternative Supply of Sulfur	V-22
V-5	Approximate Value of Iron Pyrite Delivered to Cairo Phosphate Complex, Under Selected Conditions	V-24
V-6	Net Cost of Pyrite to Cairo and Baton Rouge Locations	V-26
V-7	Allowable Pyrite Price for Different Return on Investment Requirements	V-31
B-1	Oxygen Enrichment Process Data	B-2
B-2	Oxygen Requirements vs Plant Capacity and Pyrite Feed	B-3
B-3	Total Processing Costs for Oxygen Enrichment Plants	B-6

LIST OF FIGURES

Figure No.		Page
II-1	Effect of Feed Composition on Plant Processing Costs 1500 Ton-per-Day Sulfuric Acid (98%)	II-8
III-1	Pyrite-Removal Process	III-20
III-2	Comparative Sulfuric Acid Manufacturing Costs - Brimstone vs Pyrite	III-21
III-3	Effect of Plant-Feed Composition on Total Capital Investment	III-30
III-4	Effect of Plant-Feed Composition on Plant Processing Costs	III-33
III-5	Effect of Feed Composition on Plant Processing Costs 1500 Ton-per-Day Sulfuric Acid (98%)	III-36
III-6	Flow Diagram of Fluosolids Pyrite-Roasting/Sulfuric-Acid Plant-Type I-A	III-43
III-7	Fluid-Bed Process for Reducing Pyrite to Iron	III-107
IV-1	Regions of the United States	IV-2
V-1	Regional Supply-Demand Balance for Phosphate Fertilizers, 1970-1971	V-5
V-2	Regional Comparison of Sulfur Requirements for Phosphatic Fertilizer Demand vs Sulfur Consumed within each Region for Phosphate Manufacturing, 1970-71	V-7
V-3	Expected Movements of Phosphate and Equivalent Sulfur from Surplus Production Areas, 1971	V-9
V-4	Increased Phosphate Fertilizer Demand Between 1966 and 1976, by Area with Existing Phosphate Supply Routes vs Likely Location for Phosphate Project Based Upon Pyrite from Coal	V-11
V-5	Estimated Value of Pyrite for Supplying Sulfuric Acid to Phosphate Fertilizer Plant at Cairo, Illinois	V-28

I. INTRODUCTION

A. BACKGROUND

Aside from carbon monoxide, the oxides of sulfur, principally sulfur dioxide (SO_2), are the most common air pollutants. It is estimated that approximately 27 million tons per year of SO_2 are currently discharged into the atmosphere from the following sources:

Source	Amount (millions of tons per year)		
	1963	1970	1980
Power plant operation (coal and oil)	10.1	15.6	30.3
Other coal combustion	4.5	3.9	3.2
Other petroleum combustion	4.3	4.9	5.9
Ore smelting	1.7	1.8	2.1
Petroleum refineries	1.6	1.6	1.6
Miscellaneous (coke processing, refuse incineration, coal refuse banks, etc.)	1.2	0.8	0.5
Total	23.4	28.6	43.6

Source: "Power Plant and Other Sulfur Dioxide Emissions: 1940-2000," Rohman, F.A., Steigerwold, B.J., Ludwig, J.H., ASME pub. 65-PWR-15, 1965.

Of the 23 million tons of SO_2 discharged in 1963, nearly 15 million tons occurred as a result of coal combustion, and of this amount, some 10 million tons was generated by coal-burning electrical power utilities. Depending upon the assumptions taken, projections have been made which show a near doubling of total SO_2 pollution during the period 1963-1980, a situation which could, given the proper conditions, become critical.

From the foregoing it is at once apparent that the major sources of SO_2 emissions are coal-fired power generation facilities, followed by other industrial facilities and space heating. It is also apparent that as time passes, power plants will become increasingly important potential contributors of SO_2 emissions. Thus, while the importance of other SO_2 sources cannot be ignored, the principal concern will continue to be reduction of emissions from coal-fired power generation facilities. Hopefully, much of the technology developed for this purpose can be applied to the smaller contributors.

At present, considerable research effort is being directed toward reducing the level of SO_2 in stack emissions. The National Air Pollution Control Administration is attacking the problem on a broad front by investigating four general areas that have promise for reducing these emissions: (1) removal of SO_2 from stack gases after fuel combustion,(2) removal of sulfur or sulfur-containing compounds from the fuel before combustion, (3) determination of availability and applicability of naturally occurring low-sulfur fuels, and (4) changes in in-process technology. Most of the processes under consideration are directed not only to the reduction of SO_2 emissions but also include some provision for commercial use of the sulfur values thus recovered.

The latter point is important, since it raises the possibility of making SO_2 removal commercially attractive through creating a "new" source of sulfur values. Elemental sulfur is currently in short supply throughout the free world. Since 1962, free-world sulfur consumption has outstripped production. This rapid increase in demand, estimated at 8% per year in 1966 in the

United States (the historic demand growth rate has been approximately 4.5% per year), has resulted largely from expansion of the fertilizer industry, which uses large tonnages of sulfuric acid. Sulfur prices have also increased, making more attractive to some extent the use of sulfur production methods other than the Frasch process. Further, known Frasch reserves in the United States are limited in their extent, making further development of additional sources still more necessary.

It is thus apparent that the two situations - pollution of the air with SO_2 and an imbalance in the sulfur supply/demand picture - might lend themselves to some technological/marketing approach which could result in an economically attractive answer for both problems.

B. OBJECTIVE

With the foregoing in mind, the National Air Pollution Control Administration authorized Arthur D. Little, Inc., and Dorr-Oliver, Inc., ~~to investigate~~ The report contains [illegible]ion of the economics of utilizing iron pyrite (FeS_2) obtained from coal beneficiation. The primary objectives of our study were (1) to determine the costs and revenues associated with the processing of iron pyrite removed from coal prior to combustion of the coal, and the products to be derived from such removal, and (2) to evaluate the acceptability of the process to the industries that might be involved (e.g., coal, utility, chemical, and steel).

Current projects at the National Air Pollution Control Administration are concerned with the development and evaluation of economic processes for removal of pyrite from coal and with the location of coals suited for that purpose. Accordingly, we were not asked to concern ourselves with the technology or costs associated with the process of coal beneficiation itself, nor with locating specific areas where sufficient quantities of pyrite might be economically obtained. Rather, we have attempted to develop a range of prices that might ultimately be paid to coal operators at the preparation plant for coal beneficiation that would produce a low-sulfur coal and an acceptable grade of pyrite feed material for use in sulfuric acid manufacture.

The evaluation included technical, marketing, and economic considerations, and emphasized from a geographic point of view consideration of the three major coal-producing regions in the eastern United States which are believed to have significant quantities of pyrite associated with the coal -- central Pennsylvania, southern Illinois, and northeast Ohio -- as well as those adjacent regions which could reasonably serve as markets for the products derived from pyrite.

C. APPROACH

This report has two separate but related parts:

1. Process Economics

We developed a financial measure of the advantages and disadvantages that should pertain to coal and power companies as a result of pyrite removal, including such factors as reduced sulfur pollution, reduction of handling problems, higher Btu content per ton of delivered coal, effect on precipitation equipment, and the like. Arthur D. Little, Inc., personnel conducted this portion.

The major portion of the process economics discussion is devoted to the determination of the estimated capital and operating costs of various sizes of sulfuric acid plants based on fluid bed treatment of a range of pyrite feed compositions. The effect of plant size, plant type, feed composition, and by-product credits were carefully investigated to define practical operating conditions. Dorr-Oliver, Inc., used its extensive background in fluid bed process technology in carrying out this portion of the study.

2. Market Analysis

This portion of the study, carried out by Arthur D. Little, Inc., covers the market outlook for sulfuric acid in the geographic area under investigation and includes estimated current and future demand data, production capacity, trends affecting prices and future consumption of sulfuric acid, and the most likely posibilities for new acid production facilities. Also discussed is the effect of the current domestic sulfur shortage on sulfur and sulfuric acid supply and price levels. The information developed in this phase of the study provides the framework by which the economic feasibility of a proposed venture might be measured.

D. ACKNOWLEDGEMENTS

The information sources upon which this report is based are numerous and varied. Numerous interviews were made with representatives of chemical, utility, steel, and coal companies and with appropriate personnel in such organizations as the Bureau of Mines, Bituminous Coal Research, Inc., and the Department of Commerce. The extensive background of both Dorr-Oliver, Inc., and Arthur D. Little, Inc., in their respective fields was used to a considerable degree.

The project director for the study was Mr. Richard W. Hyde of Arthur D. Little, Inc. He was assisted by Messrs. Bruce M. Putnam, M.C. Manderson, Samuel C. Fleming, and Harry W. Trask. Mr. Clarence J. Wall of Dorr-Oliver, Inc., was responsible for that company's portion of the report.

The study was performed under the supervision of Mr. T. Kelly Janes, Project Officer, and Mr. Paul W. Spaite, Chief, Process Control Engineering Program, National Air Pollution Control Administration, U.S. Department of Health, Education, and Welfare. The advice and direct assistance of these gentlemen is sincerely appreciated.

II. SUMMARY

A. PROCESS ECONOMICS

It should be recognized that because of their importance as large-volume users of coal, and therefore as the major actual and potential source of SO_2 pollution, coal-burning electrical power utilities were assumed to be the "only" potential users of de-pyritized coal for the purpose of this study. Obviously, such is not the case. Smaller coal users (small privately owned power stations, industrial and commercial heating plants, etc.) might possibly be the most significant customers for low-sulfur (de-pyritized) coal. Because of their size and location and the fewer options available to them regarding air pollution abatement requirements, they are faced with similar problems. Moreover, these users are frequently located in densely populated urban areas, where pollution abatement needs are usually the most severe.

The use of a low-sulfur coal by such firms, even at a higher price, might well constitute the least expensive solution to their problem. Other alternatives, such as relocation, construction of taller stacks, or installation of stack gas treating equipment, involve capital expenditures which, in many cases, are relatively more significant to the small company.

In brief, we believe that the use of a pyrite feed derived from coal to make sulfuric acid is technically possible. The economic feasibility of the process - in essence, the amount that can be paid for the pyrite feed expressed in terms of dollars per ton of processed coal - is dependent upon a number of interrelated factors, including the price of elemental sulfur and of sulfuric acid, location of the acid plant relative to the pyrite deposits, expected return on investment, and of course the markets for sulfuric acid. Taking these and other considerations into account (including an f.o.b. price for elemental sulfur of $38.00 per long ton), we estimate the net financial benefits to coal operators for producing low-sulfur (1% or less) coal and an acceptable pyrite feed material could range from $1.16 to $1.57 per ton of coal processed. The results of our study are summarized below and given in detail in the following sections.

1. Pyrite Coal Beneficiation

a. Premiums for Low-Sulfur Coal

We believe it reasonable to expect that a premium of $1.10-$1.20 per ton of coal should be obtained by mines supplying low-sulfur coal (less than 1% sulfur) to utilities subject to stringent air pollution abatement restrictions. Of this amount, approximately $0.30 represents the net value of the coal to a utility (or other coal user) after weighing the advantages (higher heating value, reduced refuse disposal, etc.) and disadvantages (additional handling equipment, reduced efficiency of precipitators, etc.). The balance, $0.80 - $0.90, represents the premium connected with achieving lower sulfur content in the stack gas and thereby reducing SO_2 pollution of the atmosphere.

At the present time, most midwestern utilities are not faced with pollution abatement requirements as demanding as those in the East, and hence are currently reluctant to pay an "anti-pollution premium" of $0.80-$0.90 per ton of coal. However, recent indications suggest that more stringent regulations will be forthcoming in the Midwest (e.g., St. Louis, Kansas City, Chicago), and that therefore the premiums paid for low-sulfur coal will approximate those paid by eastern utilities. Because of this situation, we have assumed one low-sulfur coal premium, $1.10-$1.20 per ton. In general, we believe that this premium could, and should, also be paid by the majority of non-utility coal users.

b. Benefits to Coal Producers

Coal companies themselves, through reducing the pyrite content of the coal, should obtain a benefit of approximately $0.15 per ton of coal processed -- $0.10 per ton from reduced disposal requirements, and $0.05 per ton as a result of minimization of air and water pollution problems associated with the refuse piles. A summary of the net benefits to mines and utilities arising from coal-depyritization is presented in Table II-1.

c. Location of Pyrite-bearing Coal Deposits

The location of a suitable coal preparation plant for pyrite removal and of a pyrite-based sulfuric acid plant will be influenced by the location of large coal deposits which best lend themselves to pyrite beneficiation. At the present time, there are insufficient data to permit precise identification and evaluation of such deposits; other projects are underway to answer these questions. Accordingly, for purposes of this study, location of the acid plant was determined largely by market conditions so long as that location fell within the Appalachia-Southern Illinois region.

d. Volume of Coal Required for Economic Processing

In order to support a 1500-ton-per-day sulfuric acid plant (the minimum size we believe to be suitable for economic manufacture under most conditions), considerable tonnages of pyrite-bearing coal must be processed. Assume, for example, a feed stream containing 85% pyrite, a requirement of 1550 pounds

TABLE II-1

SUMMARY OF ADVANTAGES AND DISADVANTAGES TO UTILITIES AND MINES IN USING LOW-SULFUR COAL

Utilities	Savings (cents per ton)
Advantages	
Higher heating value per ton	15 - 25
Easier to pulverize	0 - 4
Improved maintenance	1 - 15
Less ash disposal	5 - 10
Disadvantages	Cost (cents per ton)
Less efficient precipitators	1 - 15
Added handling costs for pulverized coal	0 - 15
Net Tangible Value	(-) 9 - (+) 53 (Est avg = 30)
Reduce SO_2 pollution	+ 80 - 90
	$1.10 - 1.20
Mines	
Reduced disposal requirements	10
Minimization of air and water pollution problems associated with refuse piles	5
	15
Total Estimated Net Benefit	$1.25-1.35/ton of coal

of feed per ton of 98% acid produced, an original total sulfur content in the coal of 4% (3% inorganic, 1% organic), and a coal yield of 90%; then 5.1 million tons per year of coal would have to be beneficiated to yield a 1% sulfur content coal, or 7.6 millions tons for a 1-1/2% sulfur content. The largest mine in the United States (1966 figures) produces 5.6 million tons per year. Presumably, therefore, pyrite would have to be collected from coal preparation plants serving more than one mine. This in turn raises the question of transportation and process costs vis á vis the price obtainable for the pyrite.

2. Sulfuric Acid Manufacture

Costs associated with the manufacture of sulfuric acid from a pyrite feed will vary primarily as a function of three major variables: plant size, plant type, and feed composition. Plant size and type will be determined to a considerable degree by market conditions expected to prevail over the life of the project. However, the nature of the feed stream could change in accordance with raw material sources and beneficiation processes.

a. Effects of Feed Composition

Since the pyrite source and means of beneficiation were unknown, a broad range of possible pyrite feed compositions were arbitrarily selected and evaluated. These feeds and their approximate mineral content are shown below.

Feed No.	% Pyrite	% Coal	% Gangue
2	90	5	5
4	80	7	13
6	85	10	5
8	70	10	20
10	70	15	15
12	65	23	12

The pyrite feed composition has a pronounced effect on almost all of the process requirements in both the pyrite roasting section and in the contact acid section. As the grade of feed decreases (less pyrite, more coal), the process requirements (and therefore capital and operating costs) are affected as follows:

(1) Amount of feed per ton of product acid increases;

(2) Volume of air required for roasting per ton of product acid increases;

(3) Volume of product gases per ton of product acid increases in all sections of the plant;

(4) SO_2 gas strength or percentage decreases in the product gas with increased CO_2 and water from coal oxidation; and

(5) Steam generation per ton of product acid increases.

The pyrite/coal ratio has the major effect upon process requirements. The amount of gangue has only a minor effect, in that the material essentially does not enter into the chemistry of the roasting process; the principal effect of gangue is with respect to the amount of feed required and the amount of calcines produced. This relationship is shown in Figure II-1.

While the costs of pyrite-coal beneficiation must ultimately be taken into account, we believe that for practical purposes a feed composition of no worse than No. 8 (70% pyrite, 10% coal, 20% gangue) should be used for acid manufacture. For purposes of this study, we used feed No. 6 (85% pyrite, 10% coal, 5% inerts), which we believe represents a reasonable composition to expect, although feeds may vary over time in actual practice.

b. Costs

Since the location of the precise pyrite source or sources and detailed estimates of beneficiation costs were unknown, it was decided that manufacturing costs would assume pyrite on the plant site, free of any production or freight charges. In addition, byproduct credits, such as for iron calcines, were not included in the basic cost estimates, since reasonably firm markets for such byproducts could not be identified (estimates of possible byproduct credits were prepared, however).

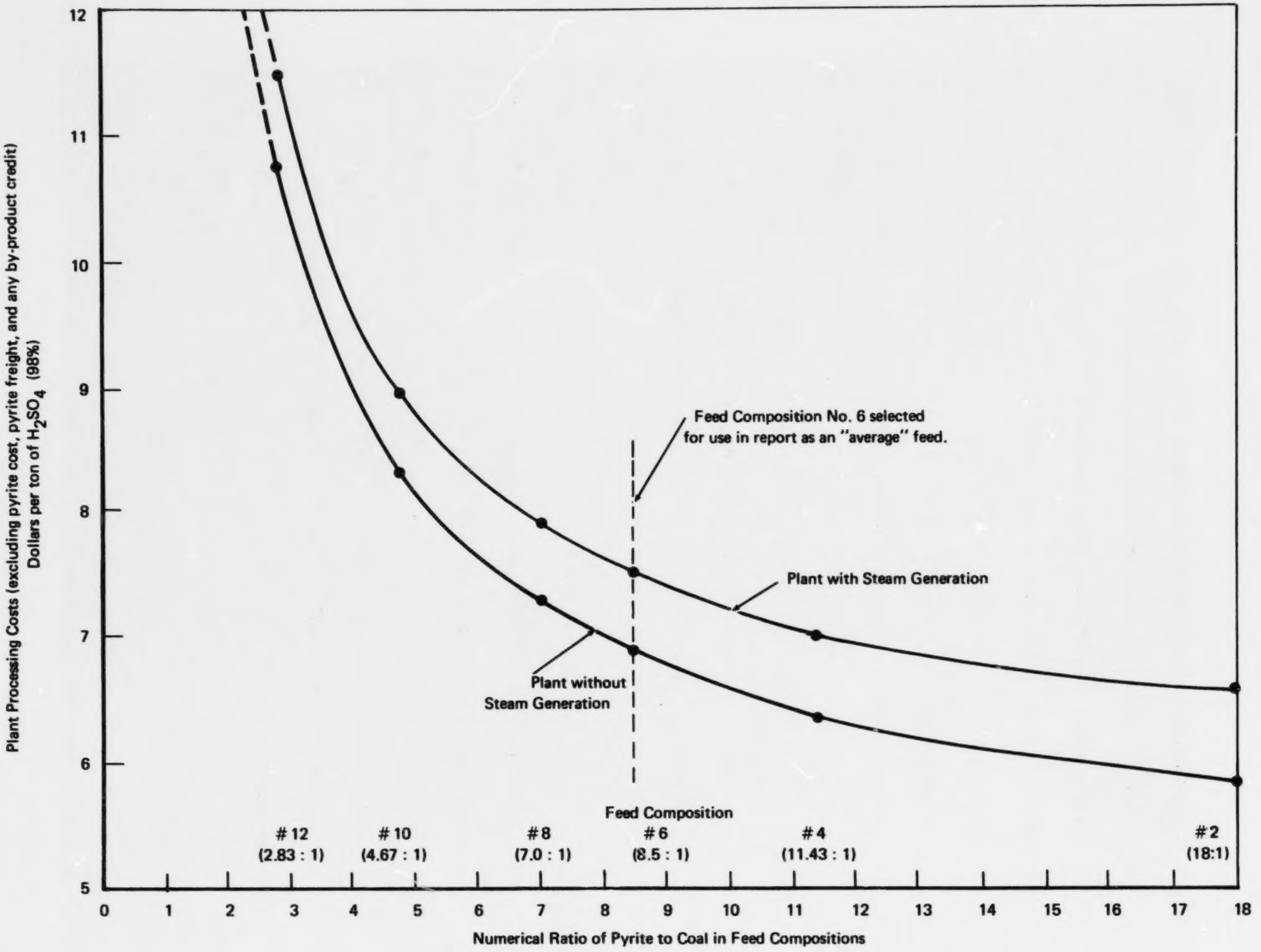

FIGURE II-1 EFFECT OF FEED COMPOSITION ON PLANT PROCESSING COSTS
1500 TON-PER-DAY SULFURIC ACID (98%)

On the basis of the three major parameters -- plant capacity, feed composition, and plant type -- investment and operating costs were calculated for each possible combination. The results are shown in Tables II-2 and II-3. Manufacturing costs (excluding cost of pyrite) range from a low of $5.51 per ton of 98% sulfuric acid to $25.40 per ton, and plant investment from $3.7 million to $35.5 million.

Market data indicate that the trend in new sulfuric acid plant construction is toward larger capacities. For purposes of our study with regard to economic use of pyrite-based sulfuric acid we selected a 1500-ton-per-day plant, Type 1A (equipped with waste heat boiler and cooling tower) and feed No. 6. Estimated processing costs (excluding raw material costs and any byproduct credit) for this type of plant are $7.63 per ton of 98% acid produced, and estimated plant investment is $14.54 million.

c. Byproduct Credits

The principal byproduct credits that might be obtained from making sulfuric acid from pyrite are low-pressure steam and iron oxide (either as calcines or as pellets). The steam will have a value only if there is a nearby market for it or unless the acid plant is part of a larger integrated operation. In the study, no specific credit for byproduct steam was included in the cost estimates, since the exact disposition of the steam was uncertain.

TABLE II-2

Total Processing Costs (Direct & Indirect Costs) (Dollars Per Ton of 98% Product Acid)
vs.
Pyrite Plant Feed Composition and Plant Capacity

		Pyrite Plant Feed Composition Number											
		2		4		6		8		10		12	
%Pyrite		90		80		85		70		70		65	
%Coal		5		7		10		10		15		23	
%Inerts		5		13		5		20		15		12	
S/C Ratio		13.8		8.7		6.5		5.36		3.58		2.2	
S/H_2 Ratio		182		116		86		71		47.5		29	
Plant Type →		IA	IIA	IA	IIA	IA	IIA	IA	IIA	IA	IIA	IA	IIA
										Approx.		Order of Mag.	
Plant Capacity - TPD (98%) Acid													
Plant Type I	Plant Type II												
250	258	18.11	15.63	18.92	16.57	19.59	17.17	20.11	17.73	21.61	19.23	24.53	22.21
500	517	10.74	9.47	11.34	10.08	11.76	10.52	12.15	10.90	13.66	12.62	15.74	14.65
1000	1033	7.75	6.92	8.27	7.43	8.63	7.82	9.31	8.46	10.22	9.41	12.29	11.62
1500	1550	6.60	5.92	7.07	6.38	7.63	7.00	7.90	7.32	8.97	8.35	11.53	10.76
2500	2583	6.20	5.51	6.88	6.20	7.20	6.53	7.72	7.03	8.74	8.02	11.14	10.32
Plant Type →		IB	IIB	IB	IIB	IB	IIB	IB	IIB	IB	IIB	IB	IIB
										Approx.		Order of Mag.	
Plant Capacity - TPD (98%) Acid													
Plant Type I	Plant Type II												
250	258	18.64	16.62	19.54	17.54	20.21	18.23	20.81	18.84	22.42	20.52	25.40	23.80
500	517	11.33	10.44	11.97	11.14	12.47	11.67	12.88	12.11	14.64	13.96	16.86	16.45
1000	1033	8.34	7.91	8.91	8.55	9.34	9.00	10.07	9.70	11.10	10.86	13.42	13.49
1500	1550	7.20	6.93	7.72	7.51	8.34	8.21	8.68	8.58	9.87	9.84	12.65	12.70
2500	2583	6.80	6.56	7.54	7.36	7.92	7.78	8.49	8.34	9.64	9.52	12.29	12.28

Plant Type		
	I-A	Cooling tower and steam generation equipment.
	I-B	Steam generation equipment but no tower.
	II-A	Cooling tower, no steam generation equipment.
	II-B	No cooling tower, no steam generation equipment.

TABLE II-3

Battery Limit Costs and Total Capital Investment vs.

(Millions of Dollars)

			Pyrite P				
			2		4		
Capacity Factors (See Table 6)			1.0		0.897		
	TPD Capacity	TPY (98%) Acid	Bat. Lim. Cost	Tot. Cap. Invest.	Bat. Lim. Cost	Tot. Cap. Invest.	Bat. Lim Cost
Plant Type IA { Steam, Cooling tower							
	250	82500	3.16	4.14	3.52	4.60	3.80
	500	165000	4.19	5.48	4.67	6.10	5.03
	1000	330000	6.97	9.12	7.75	10.19	8.35
	1500	495000	9.21	12.10	10.26	13.50	11.04
	2500	825000	14.39	18.86	16.04	21.00	17.30
Plant Type IB { Steam, No cooling tower							
	250	82500	3.11	4.07	3.47	4.54	3.74
	500	165000	4.11	5.39	4.59	6.00	4.93
	1000	330000	6.85	8.96	7.65	10.00	8.22
	1500	495000	9.06	11.89	10.10	13.24	10.86
	2500	825000	14.18	18.55	15.96	20.70	17.05
Plant Type IIA { Cooling tower No steam							
	258	85000	2.87	3.82	3.20	4.27	3.44
	517	170600	3.76	5.00	4.18	5.58	4.50
	1033	340900	6.05	8.05	6.75	8.98	7.26
	1550	511500	7.89	10.50	8.79	11.70	9.48
	2583	852000	12.12	16.15	13.50	17.98	14.55
Plant Type IIB { No cooling tower No steam							
	258	85000	2.76	3.67	3.07	4.08	3.30
	517	170600	3.60	4.80	4.01	5.34	4.32
	1033	340900	5.81	7.73	6.48	8.63	6.95
	1550	511500	7.57	10.08	8.44	11.20	9.09
	2583	852000	11.71	15.65	13.03	17.37	14.05

Plant Type		
	I-A	Cooling tower and steam generation equipment.
	I-B	Steam generation equipment but no tower.
	II-A	Cooling tower, no steam generation equipment.
	II-B	No cooling tower, no steam generation equipment.

TABLE II-3

pital Investment vs. Capacity and Feed Composition
Millions of Dollars)

Pyrite Plant Feed Composition Numbers

4	6		8		10		12	
.897	0.833		0.783		0.673		0.530	
Tot. Cap. Invest.	Bat. Lim. Cost	Tot. Cap. Invest.	Bat. Lim. Cost	Tot. Cap. Invest.	Bat. Lim. Cost	Tot. Cap. Invest.	Bat. Lim. Cost	Tot. Cap. Invest.
					Approx.		Order of Mag.	
4.60	3.80	4.98	4.04	5.29	4.69	6.14	5.96	7.83
6.10	5.03	6.59	5.35	7.00	6.21	8.15	7.91	10.31
10.19	8.35	10.96	9.92	11.66	10.30	13.53	13.17	17.20
13.50	11.04	14.54	11.78	15.42	13.67	17.95	17.40	22.80
21.00	17.30	22.65	18.37	24.10	21.40	28.00	27.20	35.50
4.54	3.74	4.88	4.06	5.20	4.61	6.05	5.80	7.60
6.00	4.93	6.46	5.26	6.87	6.11	8.00	7.78	10.15
10.00	8.22	10.76	8.75	11.46	10.16	13.31	12.95	16.91
13.24	10.86	14.27	11.56	15.18	13.46	17.65	17.11	22.40
20.70	17.05	22.25	14.21	23.70	21.00	27.55	26.80	35.00
4.27	3.44	4.58	3.66	4.88	4.26	5.67	5.44	7.25
5.58	4.50	6.00	4.78	6.38	5.56	7.51	7.10	9.45
8.98	7.26	9.68	7.73	10.30	8.98	11.94	11.43	15.24
11.70	9.48	12.61	10.10	13.45	11.70	15.60	14.88	19.80
17.98	14.55	19.37	15.49	20.60	18.00	24.00	22.86	30.40
4.08	3.30	4.39	3.52	4.68	4.09	5.44	5.22	6.93
5.34	4.32	5.75	4.59	6.10	5.35	7.12	6.80	9.04
8.63	6.95	9.25	7.42	9.87	8.60	11.45	10.98	14.60
11.20	9.09	12.10	9.66	12.88	11.22	14.99	14.31	19.10
17.37	14.05	18.73	14.95	19.90	17.35	23.12	22.10	29.40

tion equipment.
no tower.
tion equipment.
ration equipment.

Plant Feed Composition

No.	% Pyrite	% Coal	% Gangue
2	90	5	5
4	80	7	13
6	85	10	5
8	70	10	20
10	70	15	15
12	65	23	12

B

The market for the byproduct iron oxide will depend upon its quality, volume of production, and customer demand. Since the quality is unknown, detailed speculation on its worth was not justified. Given the current market situation, it is doubtful that any credit for the manufacture and sale of iron pellets can be expected --first, because at any level of operation under 1500-ton-per-day of acid, production would be at best a break-even proposition, and secondly, because even at the 2500-ton-per-day level, wherein a theoretical credit of $0.68 per short ton of acid might result, shipping charges and the relatively low production rate (362,000 short tons per year of pellets) could be expected to seriously reduce any expected profit.

On the other hand, a credit for iron calcine production may more reasonably be expected, since the value of the calcines, calculated at $0.08 per iron unit per ton of acid, amounts to a credit of approximately $2.08 per ton of acid. This figure allows more flexibility regarding marketing of the product and absorption of freight charges. Of course, the value of this material is also dependent upon the percentage of contaminants contained in the calcines (e.g., sulfur, arsenic, cobalt, etc.), with lower percentages being the more favorable. Because of the uncertainties involved regarding calcine production and sale, a direct iron credit was not included in assessing the economics of a pyrite-based operation.

B. SULFURIC ACID MARKET

1. End Uses

Because of its comparatively high weight and low price (ranging between $15 and $25 per ton f.o.b. plant), sulfuric acid is ordinarily marketed within a radius of 150-200 miles. Within the eight-state area covered by our study, the major outlet for sulfuric acid today and in the foreseeable future is and will be the phosphate fertilizer industry, which presently consumes approximately 40% of all sulfuric acid manufactured and sold in the United States. Of the other uses of sulfuric acid, ammonium sulfate (also used extensively in fertilizer manufacture), titanium dioxide, petroleum refining, and steel making are the most significant. End-use distribution of sulfuric acid is given in Table II-4.

Ammonium sulfate production is expected to increase slightly during the next five years or more. On the other hand, the outlook for sulfuric acid consumption in the steel industry is not encouraging; there is mounting pressure to reduce the amount of sulfuric acid consumed in the steel pickling process. The use of sulfuric acid in the petroleum refining industry is increasing at a rate of about 4% annually, primarily due to the sulfonation of lube oils and petroleum additives. In titanium dioxide, a long-term trend toward decreasing use of sulfuric acid is foreseen because of the increasing acceptance of the chlorination route to manufacture, at the expense of the sulfate-based process which uses sulfuric acid.

TABLE II-4

SULFURIC ACID DISTRIBUTION BY END-USE
(thousands of tons, 100% H_2SO_4)

	1963	1964	1965	1966	Percent of Total
Phosphate Fertilizers	6,906	7,753	9,275	11,675	41
Ammonium Sulfate	1,390	1,759	1,967	1,885	7
Titanium Dioxide	1,951	1,975	1,900	1,740	6
Petroleum - Alkylate Refining	1,325	1,375	1,400	1,435	5
Petroleum - Other Uses[1]	1,130	1,205	1,260	1,335	5
Iron and Steel Pickling	1,084	1,190	1,075	1,000	3
Hydrofluoric Acid	603	630	710	785	3
Rayon and Cellophane[2]	839	885	895	836	3
Alcohols	599	631	665	700	2
Aluminum Sulfate	536	574	580	592	2
Synthetic Detergents	481	500	510	530	2
Copper and Uranium Leaching and Processing	607	576	567	550	2
Dyes and Intermediates	294	312	330	350	1
Explosives[3]	146	118	100	198	1
Other Chemicals	2,697	2,951	3,099	3,389	12
Exports	7	14	7	-	
Miscellaneous	1,165	1,302	1,360	1,500	5
Total	21,760	23,750	25,700	28,500	100

1. Includes sulfonated petroleum lube oil additives and other petroleum products.
2. Includes other cellulose film, sheets, or products.
3. Excludes mixed acid, which is included in other chemicals for 1963, 1964, 1965.

Sources: U.S. Department of Commerce, 1963-65; Arthur D. Little, Inc., 1966.

Other markets, including rayon and cellophane, detergent, and explosive manufacture, can have major significance in individual marketing areas, but in most respects are supplied on a captive basis, or through closely tied contracts.

Phosphatic fertilizer consumption is expected to increase over the next ten years at a national rate of approximately 4% per year. The largest phosphate-consuming areas in the United States are now located in the upper Midwest. Requirements in this region of the country are expected to grow at a faster rate than national consumption - on the order of 8-10% per year.

The size of phosphate fertilizer plants is steadily increasing, with new projects being designed for P_2O_5 capacity of 200,000 tons-per-year, equivalent to a yearly H_2SO_4 requirement of 540,000 tons (1500-1600 tons-per-day). While there are significant tonnages of merchant acid available, fertilizer manufacturers generally desire to secure captive sulfuric acid production. This in turn constitutes an opportunity for construction of a new acid plant. For these reasons, we have emphasized consideration of the fertilizer industry as a potential user of the sulfuric acid which would be manufactured from pyrites.

2. Sulfur and Sulfuric Acid Prices

December, 1967, prices were $38 per long ton of "dark" sulfur, f.o.b. Gulf Coast producing points, a considerable increase from 1964 prices of $23 per long ton. (On March 1, 1968, prices for dark sulfur were raised to $41 per long ton.) Domestic sulfur supplies are limited, and many sulfuric acid plants have had difficulty obtaining sufficient supplies at list prices.

The December 1967 f.o.b. list price for 98% acid in tank cars was $32.75 per short ton. Yet, assuming sulfur at $42 per long ton delivered ($38 plus freight to a distant point), a 1500-TPD plant, and a 20% pre-tax return on investment, we estimate the cost of acid to be $17.00 per short ton. It is therefore reasonable to suppose that acid prices vary widely, and this is in fact the case.

Among the factors affecting prices are raw material costs and availability, production methods and costs, shipping distances, required rates of return, volumes produced, production method, purity and grade of acid, volumes purchased, reprocessing requirements, whether the acid is to be used captively or by outside customers, and, if the latter, contractual arrangements.

Definitive price data are considered confidential information by both producers and buyers; we have, however, developed our own estimates. Assuming an acid production cost of $14.92 per ton (excluding return on investment of $2.20 per ton), we estimate that captive acid is valued at between $15 and $20 per ton, and that most merchant sales are made at prices between $20 and $26 dollar per ton, including freight. We believe these prices to be typical of those in the eight-state area covered in this report.

The combination of a domestic sulfur shortage and higher prices has had other results besides causing acid prices to rise. It has also intensified interest in obtaining new sulfur supplies and/or utilizing processes which are less dependent upon the use of sulfur or sulfuric acid. Among the projects in the

United States alone which are underway or being considered to make available sulfur or sulfur values are the following:

United States

- Reactivation of Frasch mines on the Gulf Coast.
- Development of new sulfur deposits in West Texas.
- Installation of a gypsum-based sulfur production process in West Texas.
- Recovery of sulfur from crude oil and natural gas.
- Production of sulfuric acid from western pyrite sources.
- Production of sulfuric acid from gypsum.
- Recovery of sulfur values from SO_2 in stack gases.
- Use of nitric instead of sulfuric acid to produce phosphatic fertilizers.
- Increased furnace acid production for use in fertilizer production.

Additional programs are underway in other parts of North America and the free world.

While the timing of these projects and their impact upon sulfur supply are largely uncertain, the fact remains that current prices have stimulated many of them. We believe one or more significant new sulfur (or sulfur-value) sources will become available within the foreseeable future, certainly within the next five years. People knowledgeable in the sulfur industry with whom we have talked agree; further, the opinion of these individuals is that it is unlikely sulfur prices will rise beyond $45-50 per long ton over the next five years and that beyond that time prices will probably decline as a result of the development of new sulfur sources or processes which reduce the need for that material.

We therefore believe that the five-year outlook for sulfur and sulfuric acid prices is generally favorable, and during this time prices will remain firm or increase moderately. Beyond 1972, increasing downward pressure on sulfur prices -- and therefore on sulfuric acid -- will be felt.

3. Specific Marketing Areas

To evaluate the need for a pyrite-based sulfuric acid plant, we investigated four major marketing areas which are reasonably close to the potential pyrite source areas: Pittsburgh, Pennsylvania; Cairo, Illinois; St. Louis, Missouri; and Chicago, Illinois.

Details regarding the sulfuric acid supply/demand situation in each of the four marketing areas are given in Chapter IV. In brief, Pittsburgh is too far away to serve as an economic supply point to the Midwest fertilizer market, and an imbalance of 1.1 million tons production capacity to 900,000 tons annual demand does not offer significant opportunity to a new acid supplier.

The other three areas, Chicago, St. Louis, and Cairo, offer reasonably attractive possibilities for a large, new sulfuric acid plant, so long as all or a major portion of production would be captive and related to fertilizer production. Accordingly, we attempted to locate the acid plant with reference to potential pyrite supply and still be in a position to compete effectively in the fertilizer industry. These factors indicated the St. Louis or Cairo areas as being preferable. Since Cairo is closer to possible pyrite sources in Pennsylvania and southern Illinois (thereby minimizing potential freight costs), it was selected as the location to consider regarding an integrated pyrite-based fertilizer operation.

C. INTEGRATED PYRITE-BASED FERTILIZER MANUFACTURING OPERATION, CAIRO, ILLINOIS

In order to evaluate the effect of a pyrite-based operation on the economics of removal of pyrite from coal, a hypothetical situation was developed wherein phosphate fertilizer would be produced at Cairo, using pyrite feed obtained either from southern Illinois or the Pennsylvania region. To assess the competitive situation, an alternative was calculated, involving a similar phosphate fertilizer plant but using brimstone (elemental sulfur), and located either in Cairo or Baton Rouge, Louisiana. For purposes of discussion, the price of brimstone was assumed to be $38.00 per long ton, f.o.b. Gulf Coast port (December 1967 quoted price). These alternatives were then compared to estimate the price that might be paid for pyrite delivered to the Cairo plant. The results of this exercise were as shown in Table II-5.

Under the conditions assumed, the net price payable to a coal company for an 85% pyrite feed may range from a negative value of $1.50 per ton (i.e., "free" pyrite including transportation) to approximately $3.73 per ton. If an additional penalty is imposed on the pyrite operation to reflect the risk associated with the higher capital costs required, the prices payable for pyrite become lower.

TABLE II-5

SUMMARY OF ESTIMATED F.O.B. PRICES FOR PYRITE PAYABLE AT CAIRO, ILLINOIS IN A COMPETITIVE SITUATION

	Baton Rouge Brimstone vs Cairo Pyrite		Cairo Brimstone vs Cairo Pyrite	
Manufacturing cost advantage to pyrite-based operation	$2.42/ton pyrite, delivered		$5.65/ton pyrite, delivered	
Include cost of capital (10% pre-tax return on investment)[1]	-1.42		-1.42	
Net advantage to pyrite-based route	$1.00/ton pyrite, delivered		$4.23/ton pyrite, delivered	
Deduct Freight Costs for Delivering Pyrite:			Deduct Freight Costs for Delivering Pyrite:	
	Pyrite from S. Ill.	Pyrite from Penn.	Pyrite from S. Ill.	Pyrite from Penn.
Water Transp.[2]	-	$2.00/ton	-	$2.00/ton
Land Transp.[3]	0.50	.50/ton	0.50	.50
Total Freight	$0.50/ton	$2.50/ton	$0.50/ton	$2.50/ton
Net Estimated f.o.b. Price Payable for Pyrite (delivered cost less freight):	$0.50/ton	(-) $1.50/ton	$3.73/ton	$1.73/ton

1. 10% pretax return imposed on both alternatives. No additional penalty imposed in this calculation to reflect the higher investment costs associated with the pyrite option.
2. Source: Barge rates, Pittsburgh - Cairo, as estimated by barge companies.
3. Source: Assumed estimate - no data available since pyrite source and location not identified.

Obviously, brimstone prices will have a direct bearing on the price that might be afforded for pyrite. If sulfur prices rise, the pyrite alternative becomes more attractive; if prices decline, a pyrite-based operation is less attractive.

As previously indicated, considerable tonnages of coal must be processed to obtain the pyrite feed material. If a ratio of 17 tons of coal processed to one ton of pyrite feed obtained is assumed (based upon an industry estimate regarding Kittanning coal in western Pennsylvania), the potential income per ton of coal beneficiated accruing to a coal company through direct sale of an 85% pyrite feed would range from a negative of $0.09 per ton to a positive $0.22 per ton as shown below:

Baton Rouge Brimstone versus Cairo Pyrite		Cairo Brimstone versus Cairo Pyrite	
Pyrite from S. Ill.	Pyrite from Penn.	Pyrite from S. Ill.	Pyrite from Penn.
$0.50/ton of pyrite	(-) $1.50/ton of pyrite	$3.73/ton of pyrite	$1.73/ton of pyrite
divided by 17 tons coal/ton of pyrite obtained			
$0.03/ton of coal	(-) $0.09/ton of coal (negative)	$0.22/ton of coal	$0.10/ton of coal

D. SUMMARY OF ESTIMATED INCOME PER TON OF LOW-SULFUR COAL RESULTING FROM PYRITE BENEFICIATION AND UTILIZATION

Table II-6 summarizes the net payment that might accrue to a coal company which beneficiated its coal to produce approximately 1500 tons per day

TABLE II-6

ESTIMATED INCOME TO OFFSET BENEFICIATION COSTS ASSOCIATED WITH PRODUCTION OF LOW-SULFUR COAL AND AN ACCEPTABLE PYRITE FEED MATERIAL

(dollars per ton of coal processed)

	Mine	Utility	Acid-Fertilizer Plant Complex[1]
Reduced disposal	$0.10		
Pollution abatement	0.05	$0.80 - $0.90	
Increased Net value of low-sulfur coal		0.30	
Estimated delivered pyrite price			Negative price ($0.09) to $0.22
	$0.15	$1.10 - $1.20	minus $0.09 to plus $0.22

Total: $1.16 - $1.57/ton of coal to mine

1. Major Assumptions: Captive 1500-TPD acid plant in Cairo, Illinois.

Brimstone price: $38/long ton f.o.b. Gulf Coast.

10% pretax return on investment

Freight charges for pyrite from $0.50 to $2.50 per ton of pyrite, depending upon location of source.

of 85% pyrite feed material and a low-sulfur (approximately 1+%) coal. Depending upon the situation, we estimate that payments would range between $1.16 and $1.57 per ton of coal processed. This income would presumably be available to the coal company to offset its coal and pyrite beneficiation costs.

It should be emphasized that of the total potential income calculated under the assumption made, a maximum of $0.22 per ton, or about 15%, is related to the use of pyrite; the balance is associated with the beneficiation and sale of low-sulfur coal. In effect, sulfuric acid manufacture serves to utilize the pyrite in a useful manner; except insofar as acid production must be a viable, economically feasible process, it is not the major contributor of financial benefits to coal desulfurization by pyrite removal. Indeed, significant changes in such factors as sulfur prices or expected returns on investment effect relatively small changes in the total net benefits that might be expected by the coal operator. On the other hand, these changes have a major effect on the economics of a pyrite-based chemical operation.

These observations, in turn, raise the question of the extent to which a coal company might absorb a portion of the raw material costs which the acid plant might otherwise have to bear so that the plant could continue economic operation. The answer to this question will in large measure depend upon the feasibility and costs associated with coal beneficiation and pyrite preparation.

III. PROCESS ECONOMICS

The economics of three processes are relevant:

(1) The beneficiation of coal to produce a low-sulfur coal by removing pyrite;

(2) The beneficiation of the pyrite removed from the coal to provide a suitable raw material for the manufacture of sulfuric acid; and

(3) The roasting of pyrite to manufacture sulfuric acid.

The details and economics of the sulfuric acid process are discussed in a later section of the report.

A. ECONOMICS OF BENEFICIATION PROCESSES

Coal and pyrite beneficiation would be done by a coal company. The economics of the beneficiation processes depend on:

(1) The sulfur content of coal

(2) Location of pyrite-bearing coals

(3) Ease of pyrite removal

(4) Amount of coal that must be processed

(5) Credits for removal of pyrite:

- For low-sulfur coal
- For beneficiated pyrites
- For eliminating pyrites disposal

We were not asked to investigate actual coal or pyrite beneficiation processes. We were to assume that sufficient pyrite of appropriate composition to make commercially attractive quantities of sulfuric acid could be obtained from western Pennsylvania, eastern Ohio, or southern Illinois coals.

Thus, the primary goal of our study of the economics of the beneficiation processes has been to establish the credits that a coal company might realize from producing and selling low-sulfur coal and the pyrite removed from the coal.

1. Sulfur Content of Coal

The purpose of pyrite removal is to reduce significantly the sulfur content of the clean coal so that when the coal is burned, air pollution from sulfur dioxide is minimized. In the evaluation of coals as potential pyrite sources, only coals with low organic sulfur content (1% or less) should be considered, because mechanical cleaning of the coal cannot reduce the organic sulfur content.

Large sulfuric acid plants (1000 tons per day or more) realize significant economies of scale. Because large quantities of pyrite are needed to supply the raw material for large acid plants, the best coals as sources of pyrite are those with a relatively large (3% or more) total sulfur content and a pyritic sulfur content that can be readily removed by mechanical coal-cleaning processes.

Thus, the coals which should serve as the best sources of pyrite to make sulfuric acid are those with more than 3% total sulfur content, less than 1% organic sulfur content, and pyritic sulfur content that can be readily removed by conventional coal-cleaning methods.

2. Location of Good Pyrite Sources

The location and productive capacity of "pyrite-rich" coal mines will obviously have an important bearing on the ultimate success of the project. Freight costs (mine to preparation plant to acid plant) are of course a major consideration, as is the number of mines which will be required to sustain a pyrite-based acid plant of a given capacity.

A recent publication details the total sulfur content and the organic, pyritic, and sulfate sulfur content for coal in 283 counties in 29 coal-producing states.[1] Data on U. S. coals presented in this publication were reviewed to determine which coals meet the criteria of greater than 3% total sulfur content and less than 1% organic sulfur content. The results indicate that approximately 75% of the mines which contain coals that meet our survey criteria are located in western Pennsylvania, eastern Ohio, and northern West Virginia.

It is important to note, however, that the data represent samples taken from mines that were operating before 1953. No data are available for mines opened since 1953, and while data on older mines could be indicative of the sulfur content of coals presently being mined in the counties surveyed, the situation may have changed over the intervening 14 years. For this reason, a comprehensive survey is being made under the direction of the National Air Pollution Control Administration, which will hopefully identify those mines capable of supplying in significant quantities coals having a low organic sulfur content and a relatively high inorganic (pyritic) sulfur content.

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[1] F.E.Walker and F.E.Hartner, "Forms of Sulfur in U.S. Coals," Bureau of Mines Information Circular 8301, U.S. Dept. of Interior, Bureau of Mines, 1966.

3. Ease of Pyrite Removal

It is hoped that pyrite removal can be accomplished by relatively conventional techniques at reasonable cost. Studies have shown that the sulfur content of some western Pennsylvania coals can be reduced from about 3.9% to 1.3% by crushing the coal to 3/8" with a coal yield of 87%.[1] Other work done for the National Air Pollution Control Administration[2] indicates that comprehensive data are lacking for the entire region under investigation. Further work under sponsorship of the National Center is currently under way to answer the question more fully. Pending the outcome of this work, we have assumed, for purposes of plant location, that coals which could be satisfactorily beneficiated could be found throughout the region.

4. Amount of Coal that must be Processed

One ton of 98% sulfuric acid requires about 1550 pounds of 85% pyrite feed as a raw material. Thus, a 1500-ton-per-day sulfuric acid plant operating 330 days per year will consume about 385,000 tons of 85% pyrite raw material. If it is assumed that the original sulfur content of coal is 4% (1% organic, 3% pyritic) and that a 90% coal yield can be obtained, the tonnages of coal required to support an acid plant can be considerable, as shown in Table III-1.

In 1966 the coal production of the largest mine in the United States (Dynamo #10, Christian County, Illinois) was about 5.6 million tons. Therefore, in order to obtain enough pyrite to supply a large acid plant, it will probably be

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1. R.E.Zimmerman and G.H. Roman, Coal Age, April 1967, p. 66.
2. HEW Contract PH-86-65-29, "An Economic Feasibility Study of Coal Desulfurization," October 1965.

necessary to collect pyrite from coal-treatment plants serving more than one mine. This problem becomes even more apparent when one considers that of the 50 largest mines in the United States (over 1.6 million tons per year), six are in Pennsylvania, six in Ohio, and eleven in Illinois.

TABLE III-1

AMOUNT OF COAL TO BE PROCESSED TO YIELD LOW-SULFUR COAL
(million tons per year)

Percentage of S Remaining in Coal	Raw Coal Tonnages Required 1%	1-1/2%	2%
500 TPD Acid	1.7	2.6	3.5
1000 TPD Acid	3.4	5.1	6.8
1500 TPD Acid	5.1	7.6	10.1
2500 TPD Acid	8.5	12.6	16.8

Basis:
98% H_2SO_4
1550 lb pyrite per ton of H_2SO_4
330 acid plant days per year
4% original sulfur content of coal (1% organic, 3% pyritic)
90% coal yield

5. Credits for Pyrite Removal

A coal company that separates the pyrite from the coal should benefit in at least three ways. First, it should be able to sell the low-sulfur coal for a premium over the cost of reducing the sulfur in the coal. Second, it should be able to sell the concentrated pyrite to an acid manufacturer for a price which will cover at least a portion of the cost of beneficiation. A third credit would be a reduction in the cost of pyrite disposal, as pyrite would be sold that otherwise would have to be discarded in a refuse pile, with the attendant problems of air and water pollution.

Not all utility plants can now burn low-sulfur coal, since utility boiler plants are designed to operate with coal of specific properties. When a coal with a lower sulfur content is used instead of that for which the boiler was originally designed, the change in operating and maintenance costs depends upon how closely the properties of the low-sulfur coal compare with those of the coal for which the boiler was originally designed. For example, a power plant that has a wet-bottom boiler (the ash is collected in molten form at the bottom of the boiler) cannot burn coals which have an ash-softening temperature higher than the operating temperatures of the furnace, because semi-fused ash will pile up on the furnace floor until the boiler is forced out of service.

Testimony given in 1967 before the Senate Public Works Committee illustrated that the ash-softening temperature of a coal usually increases as the sulfur content decreases. The increase in ash-softening temperature with sulfur reduction means that a plant using a wet-bottom boiler could not normally switch from a 3-4% sulfur coal to a 1% sulfur coal without having to rebuild the wet-bottom boiler, a procedure that would cost about as much as buying a new boiler. If the wet-bottom boiler still had a useful life remaining, rebuilding the boiler would be totally uneconomical.

It should be noted, however, that at least several instances have occurred which suggest that not all low-sulfur coals necessarily have relatively higher ash softening temperatures. For example, one eastern utility uses a low-sulfur coal from southern West Virginia in a wet-bottom boiler. In any case, this in itself is not a severe limitation to the use of low-sulfur coal (and hence the value which could accrue to coal companies in reducing the sulfur content of their coals), because most of the furnaces (perhaps 80%) being operated by coal-burning utilities are of the dry-bottom type.

Assuming then that the low-sulfur coal is technically acceptable to a utility, we have attempted to quantify the advantages and disadvantages to a utility in using low-sulfur coal.

a. Advantages in Burning a Low-Sulfur Coal

(1) Higher Heating Value -- Removal of pyrite in a coal preparation plant also reduces the amount of noncombustible matter and thus increases the heating value of the clean coal. Industrial contacts generally agree that the reduction in noncombustible matter from removing pyrite would improve the heating value of coal by 500-800 Btu per pound, or about 4-6%. Utilities are

reported to presently pay about $0.03 per ton of coal to obtain an additional 100 Btu of heating value per pound of coal burned. On this basis, therefore, the additional heating value obtained by reducing the sulfur content of coal is estimated at $0.15 to $0.25 per ton.

(2) Lower Pulverization Cost -- To remove pyrite, it may be necessary to crush the coal to at least 3/8-inch (9.423 mm) particles and perhaps smaller. (We understand that an effort is being made under the supervision of the National Air Pollution Control Administration to determine the crushing that will be needed to recover suitable quantities of pyrite.) Receiving crushed coal at the utility will result in a lower pulverization cost compared with treating uncrushed coal.

Only one (Ohio) utility could make a quantitative estimate of the savings from receiving coal that was already pulverized. It formerly burned 14-mesh (1.168 mm or 3/64-inch) coal that arrived by pipeline. It concluded that using 14-mesh coal rather than unpulverized coal resulted in a 30% longer pulverizer mill life and 10% lower mill power requirements, and that the initial coal crushing step could be bypassed altogether. The net benefit to the utility of all these savings was a reduction in operating cost equivalent to $0.04 per ton of coal. Since the size of the de-pyritized coal that would be supplied to a utility is not known at this time, we assumed a range of 0-$0.04 per ton.

(3) Reduced Corrosion -- Three types of corrosion may be reduced by lowering the sulfur content of coal. Alkali-ash corrosion causes the failure of reheater tubes in boilers. The cause of this corrosion is not well understood, but is suspected to be a function of potassium and sodium ions associated with the ash content of coal. Since the total ash content would be reduced along with pyrite removal, the alkali ash corrosion problem should also be at least partially overcome.

Sulfur in coal oxidizes and combines with condensed moisture to form sulfuric acid in the air preheaters, which corrodes the preheaters; reduction of the sulfur content in the coal should reduce significantly this sulfuric acid corrosion.

The third type of corrosion for a dry-bottom boiler is due to "wall slagging" or semi-fused ash which collects on the walls of the furnace, giving rise to corrosion and reduced boiler efficiency. As the sulfur content is reduced, the ash softening temperature increases and wall slagging should be reduced.

No utility could quantify the value of reducing these maintenance problems. No one of these three types of corrosion was regarded as serious by all utilities contacted. On the other hand, each utility at one time or another in its operating experience had had problems with at least one of these three types of corrosion.

It is clear that these types of corrosion are not well understood. The corrosion will exist in one plant using one type of coal and operating under one set of conditions; yet, when another plant uses the same coal and has similar operating conditions, no corrosion occurs.

In order to estimate the value of reducing corrosion, it is necessary first to determine the total boiler plant maintenance cost. Power production expenses for all utilities are presented in great detail in the Federal Power Commission annual report, "Steam-Electric Plant Construction Cost and Annual Production Expenses." The 1965 report indicates that coal-fired boiler plant maintenance varies between about $0.25 per ton of coal burned for newer plants burning large quantities of coal to over $1.00 per ton of coal for old plants burning small quantities.

Comments by utilities regarding what part of the total maintenance cost stemmed from the three types of corrosion ranged from "very small" to "significant." If it is assumed that the three types of corrosion identified above account for between 10% and 25% of the total maintenance cost, then the cost attributable to the three types of corrosion is between $0.03 and $0.25 per ton of coal. If it is further assumed that removing 60% of the sulfur content of coal would reduce these three types of maintenance costs by 30-60%, then the net benefit in reducing sulfur would be between $0.01 and $0.15 per ton.

(4) Reduced Ash Disposal -- Utilities normally contract with a hauler to dispose of fly ash collected by the electrostatic precipitators. The price

paid to have the hauler collect the fly ash depends upon the quality of the ash and the available markets for the ash. Ash markets are as diverse as land fill, substrata for a road, abrasive for traction in ice and snow, and raw material for cinder blocks. Our field contacts indicate that the average cost to the utility for refuse disposal is $1.00-$2.00 per ton of refuse.

Removal of pyrite typically might reduce the ash content of coal from 10% to 5%. Assuming this reduction in ash, the cost of ash disposal would be reduced from $0.10-$0.20 to $0.05-$0.10 per ton of coal.

(5) Reduced Fly Ash Erosion -- Reducing fly ash was thought by some contacts to reduce the problem of fly ash erosion which occurs as the fly ash moves past the boiler equipment, much as when water moves over rock. Most contacts, however, felt that fly ash erosion is dependent upon the velocity of the ash rather than the amount of ash. Therefore, no value is assigned to reduction of fly ash erosion because of reduction in ash content.

b. Disadvantages in Burning a Low-Sulfur Coal

For a utility using a dry-bottom boiler, there are two disadvantages to using low-sulfur coal which could result in added cost to the utility: reduced precipitator efficiency and higher coal-handling costs.

(1) Reduced Precipitator Efficiency -- The dry-bottom boiler depends upon electrostatic precipitators to collect the fly ash entrained in combustion gases. The presence of sulfur dioxide and trioxide increases the efficiency of

the electrostatic precipitators. When the sulfur content of the coal is reduced to 1%, the efficiency of the precipitators probably drops, but there is no general agreement as to how much. The cost of restoring the desired efficiency is determined by many factors, including the amount of space available to add additional precipitator plates, gas volumes and velocities, operating temperatures, and the possibility of using alternative conditioning agents (such as water vapor) which do the same job as oxides of sulfur.

A precipitator manufacturer stated that if the temperature of the gas going through the precipitator is below 265°F, the reduction in efficiency will be negligible. On the other hand, if the operating temperature is as high as 300°F, the efficiency could drop from 99% to about 92% if the utility switched to a 1%-sulfur coal from a 3%-sulfur coal.

An indication of the cost of modifying the precipitators to overcome the most serious reduction in efficiency was obtained from a midwestern utility, which said it would cost about $1-3 million to restore the precipitators' efficiency to 99% if 1%-sulfur coal was burned instead of 3-1/2%-sulfur coal. Assuming that (1) it will cost $2 million to modify the precipitators and that (2) the boiler plant, with a useful life of twenty more years (new boilers are depreciated over 33 years), burns one million tons of coal a year, then the annual straight-line depreciation of the new equipment would amount to about $0.10 per ton of coal. Capital charges for this $2 million investment would, of course, increase the annual cost even more.

We believe that frequently either the drop in efficiency will be negligible or that it will be possible to restore the efficiency of the precipitators by a relatively inexpensive change in operating conditions. However, in view of the fairly wide range of possible effects facing a utility which is considering low-sulfur coal, we estimate the cost of reduced precipitator efficiency at \$0.01-\$0.15 per ton of coal.

(2) Higher Coal Handling Costs -- All utilities contacted except one felt that finely pulverized coal could not be transported in open vehicles (trucks, barges, or railroad hopper cars) without excessive wind losses. The utilities also mentioned that fine coal creates dusting problems at the boiler which give rise to higher maintenance and a greater safety hazard due to the threat of spontaneous combustion of the dust.

One utility receives 10-mesh (1/16-inch or 1.651 mm) coal from a metallurgical coal-processing plant. The coal is shipped a short distance in open hopper cars by topping the load with a layer of screened coal. Handling problems at the boiler are minimized by blending one car of the fine coal with two cars of the screened coal.

Another possible solution to handling fine coal is the use of a plastic spray as a binder on the coal in the hopper car or barge. One chemical company offers a binder which is claimed to eliminate wind losses in transporting fine coal for as little as \$0.01 per square foot of coal surface in a hopper car. Assuming a 50-ton hopper car has about 250 square feet of surface coal, then the cost of handling fine coal would be as low as \$0.05 per ton.

No quantitative estimates of added cost for handling pulverized coal at the utility were obtained from the utilities contacted. However, the Federal Power Commission reports that coal-handling at the boiler usually costs between \$0.10 and \$0.20 per ton. If the handling of fine coal increased the costs of handling by as much as 50%, depending upon the technique used, the additional handling expenses at the utility could be as high as \$0.10 per ton in addition to the \$0.05 per ton required for plastic spray. We have therefore used a range of \$0-\$0.15 per ton of coal to cover possible higher handling costs.

c. Net Value of Low-Sulfur Coal to a Utility

Table III-2 summarizes the tangible advantages and disadvantages to utilities using low-sulfur coal in dry-bottom boilers. By subtracting the cost of the disadvantages from the value of the advantages, a net value of the low-sulfur coal of between −\$0.09 and +\$0.53 per ton of coal is obtained.

These estimates are derived from comments made by utilities and therefore may be on the low side with regard to the advantages and perhaps on the high side with regard to the disadvantages of using a new type of coal. On balance, we believe it is reasonable to assume that the average net value to a utility in burning a 1% sulfur coal in a dry-bottom boiler is about \$0.30 per ton of coal. This estimate assigns no value to the reduction of air pollution.

(1) Reduction of Air Pollution -- The largest single advantage in using low-sulfur coal is to reduce air pollution. In metropolitan areas where

TABLE III-2

SUMMARY OF TANGIBLE ADVANTAGES AND DISADVANTAGES TO UTILITIES IN USING LOW-SULFUR COAL

Advantages	Savings (cents per ton)
Higher heating value per ton	15-25
Easier to pulverize	0- 4
Reduced wall slagging Reduced alkali ash corrosion Reduced sulfuric acid corrosion	1-15
Less ash disposal	5-10
Disadvantages	**Cost (cents per ton)**
Less efficient precipitators	1-15
Added handling cost for pulverized coal	0-15
Net Value	–9- +53
	(Est. avg. = 30)

the utilities are faced with stringent anti-pollution legislation, they are trying to meet the requirements of the law at the minimum cost to their customers.

A midwestern utility is testing Combustion Engineering's stack-scrubbing process, which removes 83% of the sulfur dioxide and 99% of the sulfur trioxide and fly ash. The utility is planning to use this process on an old boiler plant where the operating cost of the process is estimated at about $0.80 per ton of coal. An eastern utility is buying naturally occurring 1% sulfur coal from southern West Virginia, and also from a Pennsylvania coal company, which has agreed to reduce the sulfur content to less than 1% by pyrite removal. For this utility, the average increase in the delivered cost of coal to obtain 1% sulfur coal is about $1.50 per ton. Added freight costs are estimated at about $0.50 per ton, making approximately $1.00 per ton the net premium paid for low-sulfur coal.

Thus, utilities faced with stringent air-pollution requirements are willing to pay more than the apparent value that they obtain in burning low-sulfur coal. The difference between the value that they obtain in burning the low-sulfur coal as cited in the above analysis and the price they are paying for alternative means of pollution control which are equivalent to burning 1% sulfur coal is the amount that they are willing to pay to meet pollution abatement requirements. Thus, based on the eastern and midwestern utility situations described above, we conclude that when faced with stringent anti-pollution legislation of the type in force today, utilities will pay a premium of $0.80-$1.50 per ton of coal in order to reduce air pollution. If it is assumed that the utility gets about $0.30

per ton of coal in added value from burning low-sulfur coal, then utilities faced with anti-pollution legislation should be willing to pay at least $0.80 plus $0.30, or $1.10 per ton for 1%-sulfur coal.

Similarly, judging from the eastern situation, the net increase in cost to the utility to obtain low-sulfur coal would be approximately $1.50 less $0.30 or $1.20 per ton of coal. This assumes that the eastern utility obtains the same increase in value from burning naturally occurring low-sulfur coal as they would obtain from burning low-sulfur coal obtained by pyrite removal.

Thus, we believe that a coal company that reduces the sulfur content of its coal to the level of 1% can expect to sell this coal to utilities faced with stringent air-pollution regulation for a premium of about $1.10-$1.20 per ton of coal.

It should be noted that a large group of utilities is not faced at present with stringent air pollution legislation. This group includes many utilities in Pennsylvania, Ohio, and Illinois. Pollution control in these areas has been voluntary and limited to the use of tall stacks and emphasis on obtaining lower-sulfur coals from coal companies without paying any premium.

We believe that a 1%-sulfur coal would be attractive to these utilities, even though today they do not face stringent air-pollution requirements. All utilities contacted expressed genuine concern about the unfavorable image they have gained among their customers and the public in general because of air pollution. The utilities indicated their desire to reduce air pollution in order to promote good will and to eliminate the need for stringent anti-pollution legislation.

At the same time, they are reluctant to pay a "full" premium of $1.10-$1.20 per ton for low-sulfur coal until required to use such coal. Some utilities have sought to solve the SO_2 problem by erecting tall stacks at a cost roughly equivalent to $0.10-$0.20 per ton of coal. Given this type of situation, we believe that these utilities would pay some premium for low-sulfur coal made up of $0.30 per ton in added value, $0.20 per ton in equivalent current pollution abatement efforts, and $0.25 per ton to reduce or delay the need for more stringent legislation. This total figure of $0.75 per ton has been accepted by several midwestern utilities.

However, these utilities -- and other coal-burning industries as well -- will ultimately be faced with regulations at least as severe as those currently in force in such areas as New York City and Kansas City. For example, the city of Chicago gives every indication that such legislation will be passed in the near future.

For this reason, we believe it reasonable to assume that all utilities and other coal-burning customers will pay -- either today or in the relatively near term -- a premium of approximately $1.10-$1.20 per ton of low-sulfur (1%) coal.

(2) Credit for Sale of Beneficiated Pyrites -- Figure III-1 presents a conceptual diagram of a coal beneficiation and subsequent pyrite-concentration process which might be used to produce the appropriate pyrite raw material. This treatment of the coal and pyrite would have to be accomplished at a cost which would permit the sale of pyrite at or below the price needed to make sulfuric acid for the same manufacturing cost as when using brimstone.

By comparing the cost of manufacturing acid by roasting pyrite with the cost of manufacturing acid from brimstone (see Figure III-2), it is possible to estimate, for a given brimstone price, what pyrite price will yield the same acid manufacturing cost. A computer program (Appendix A) was developed to make this comparison to determine what pyrite price could be paid for reasonable combinations of process variables. The variables used in the computer program are listed below.

Plant Size	Feed Composition				Delivered Sulfur Price
(TPD)	Number	% Pyrite	% Coal	% Gangue	($/long ton)
500	4	80	7	13	35
1000	6	85	10	5	40
1500	8	70	10	20	45
2500					

The costs of manufacturing acid from pyrite are from Table III-35. The plant investment costs are from Table III-21. The costs for a plant making acid from brimstone are ADL estimates. A sample calculation of the manufacturing cost for a 1500-TPD brimstone-based plant is shown in Table V-3.

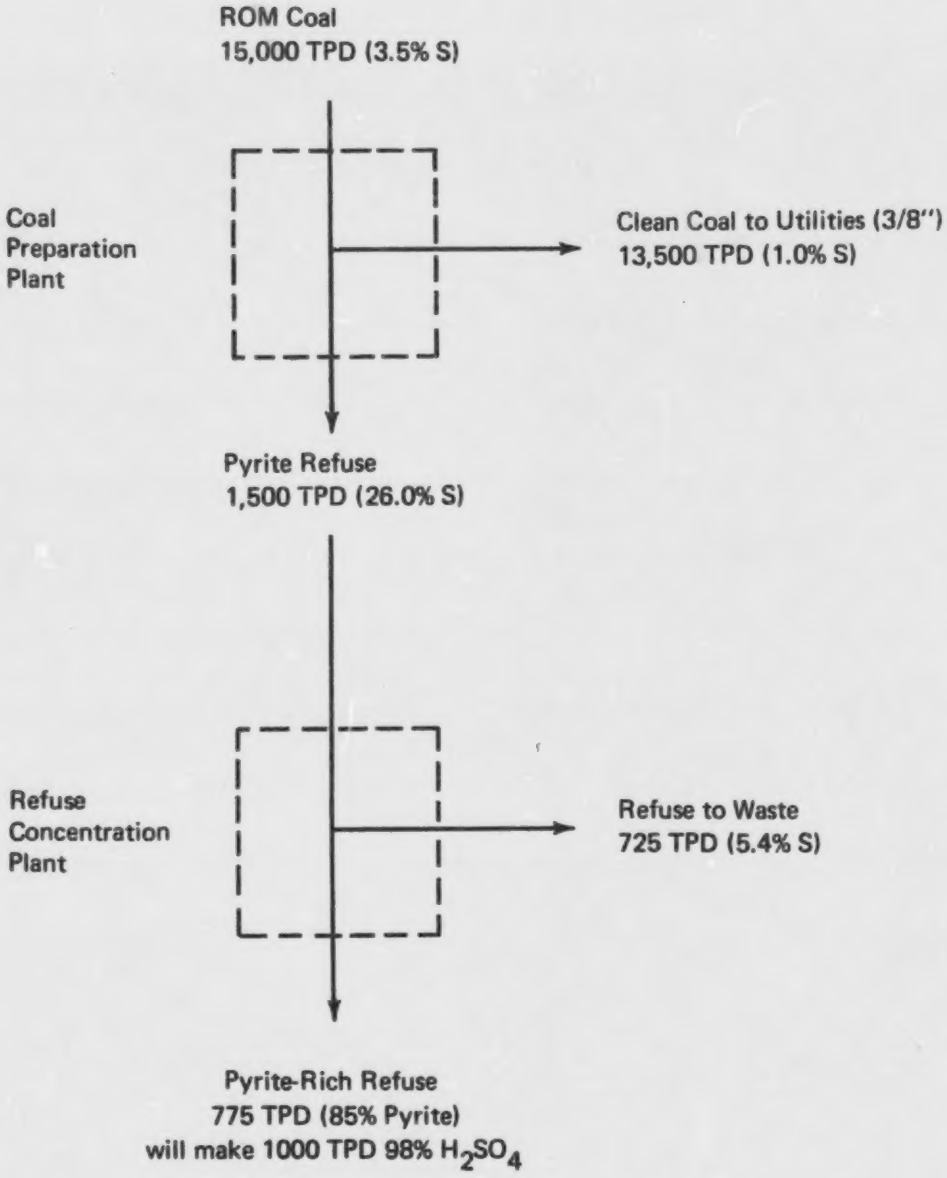

FIGURE III-I PYRITE–REMOVAL PROCESS

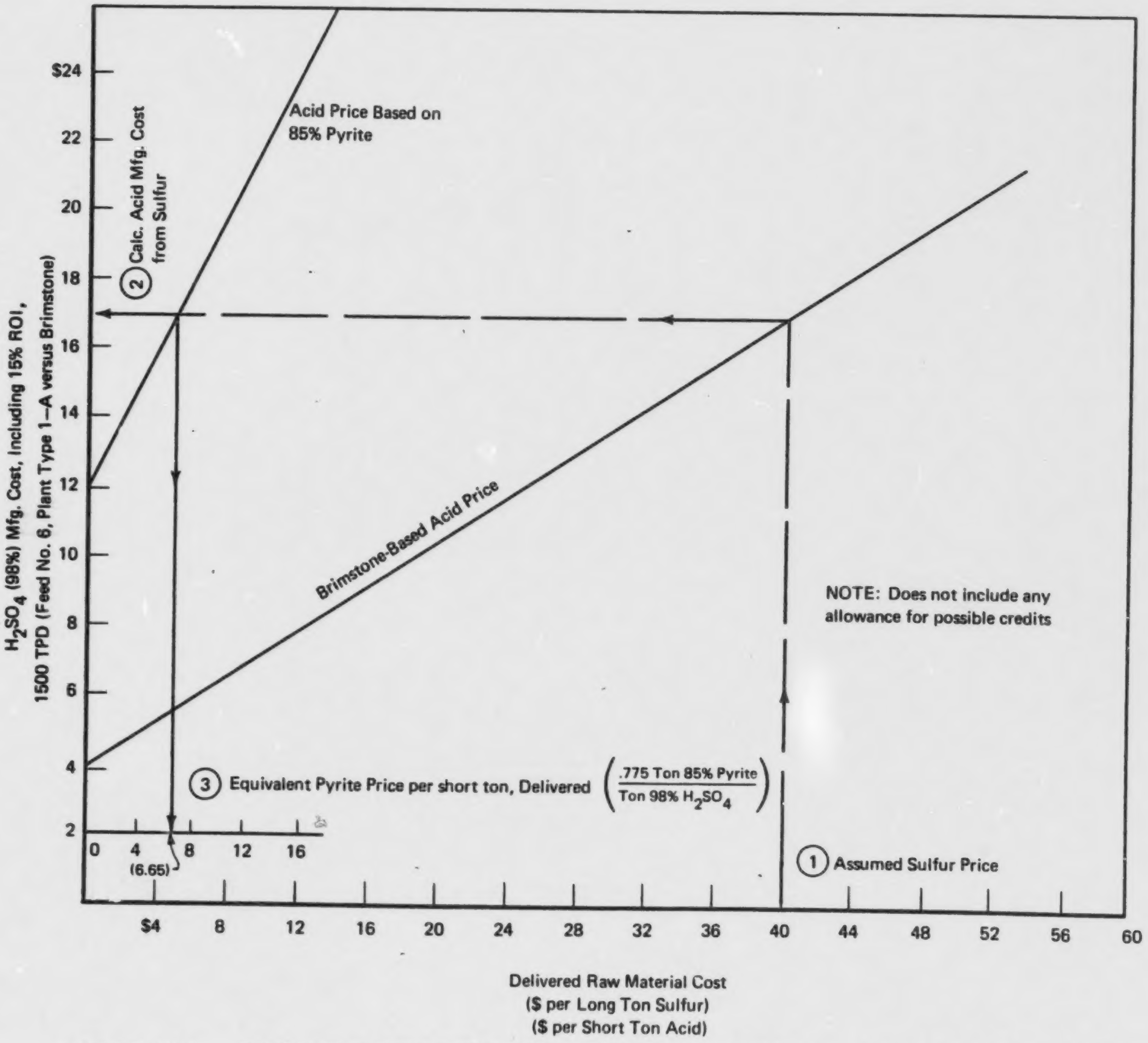

FIGURE III-2 COMPARATIVE SULFURIC ACID MANUFACTURING COSTS – BRIMSTONE VERSUS PYRITE

The results of these computer calculations are shown in Tables III-3 to III-5. If a 15% return on investment is assumed for both types of plants, the pyrite price ranges from minus $0.46 per ton for a 500-TPD acid plant using feed composition No. 8 and $35 per long ton brimstone to $9.55 per ton for a 2500-TPD acid plant using feed composition No. 4 and $45 per long ton brimstone. If a 20% return is required for the pyrite-based plant, the pyrite price ranges from minus $3.01 (500 TPD, feed No. 8, $35 per long ton sulfur) to $8.03 (2500 TPD, feed No. 4, $45 per long ton sulfur).

These pyrite prices which an acid manufacturer could pay in order to produce acid for the same price as from brimstone are based solely on a comparison between the two types of acid plants. No allowance is made for use of the acid and steam in an integrated chemical manufacturing operation. The pyrite prices which an integrated fertilizer complex could pay to give equivalent manufacturing costs with brimstone are discussed in Section V.

(3) Credit for Eliminating Pyrites Disposal -- Presently, disposal of refuse from a coal preparation plant is a problem, because coal refuse piles tend to ignite spontaneously and continue to burn. Because these refuse piles have a relatively high pyrite, and therefore sulfur, content, their burning gives off oxides of sulfur resulting in air pollution. If, instead of disposing of the pyrite-rich waste, the refuse is further concentrated as indicated in Figure III-1 and then sold as a raw material to make acid, several benefits accrue to the coal company.

TABLE III-3

THE PRICE THAT CAN BE PAID FOR PYRITES TO YIELD THE SAME SULFURIC ACID MANUFACTURING COST AS WHEN USING BRIMSTONE AT $35 PER LONG TON

Acid Plant Capacity (Short Tons Per Day)	Pyrites Feed[1] Composition	Delivered Pyrites Price ($ Per Short Ton)
500	4	1.49
1000	4	4.00
1500	4	5.24
2500	4	5.50
500	6	0.46
1000	6	3.37
1500	6	4.48
2500	6	5.10
500	8	−0.46
1000	8	1.71
1500	8	3.12
2500	8	3.36

1. A detailed breakdown of feed compositions is provided in Table III-11.

Source: Arthur D. Little, Inc., estimates.

TABLE III-4

THE PRICE THAT CAN BE PAID FOR PYRITES TO YIELD THE SAME SULFURIC ACID MANUFACTURING COST AS WHEN USING BRIMSTONE AT $40 PER LONG TON

Acid Plant Capacity (Short Tons Per Day)	Pyrites Feed[1] Composition	Delivered Pyrites Price ($ Per Short Ton)
500	4	3.52
1000	4	6.03
1500	4	7.26
2500	4	7.52
500	6	2.48
1000	6	5.54
1500	6	6.65
2500	6	7.26
500	8	1.57
1000	8	3.48
1500	8	4.89
2500	8	5.14

1. A detailed breakdown of feed compositions is provided in Table III-11.

Source: Arthur D. Little, Inc., estimates.

TABLE III-5

THE PRICE THAT CAN BE PAID FOR PYRITES TO YIELD THE SAME SULFURIC ACID MANUFACTURING COST AS WHEN USING BRIMSTONE AT $ 45 PER LONG TON

Acid Plant Capacity (Short Tons Per Day)	Pyrites Feed[1] Composition	Delivered Pyrites Price ($ Per Short Ton)
500	4	5.54
1000	4	8.05
1500	4	9.29
2500	4	9.55
500	6	4.51
1000	6	7.70
1500	6	8.81
2500	6	9.44
500	8	3.49
1000	8	5.26
1500	8	6.67
2500	8	6.91

1. A detailed breakdown of feed compositions is provided in Table III-11.

Source: Arthur D. Little, Inc., estimates.

First, by selling the concentrated pyrites, the volume of refuse produced would be reduced over 50% for the example shown in Figure III-1. The second benefit to the coal company would be that the resultant refuse, besides being smaller in volume, would have a sulfur content of about 5.6% versus 26.5% for the larger volume of refuse. Thus, even if ignition did occur, the air pollution problem would be significantly reduced, because the sulfur content would be roughly one-fourth as great. Also, with lower sulfur content, pollution of streams by drainage of dilute sulfuric acid formed by the combination of rain water and oxides of sulfur would be significantly reduced.

It should be noted that existing refuse piles from mines that have been in operation for many years contain large tonnages of pyrite-rich refuse. These refuse piles provide a potential source of pyrite to be further concentrated for use in making acid. Thus, coal companies may be able to sell old pyrite refuse which is creating an air pollution problem and taking up space which is needed to dispose of new waste material.

The superintendent of a coal preparation plant told us that although the cost of coal preparation plant refuse disposal varies widely depending upon the amount of refuse, the plant location, and the handling equipment available, the average cost of refuse disposal is in the range of $0.75 per ton of refuse. Thus, if it is assumed that the average yield in a coal preparation plant is 80% and the refuse 20%, the cost of refuse disposal is about $0.15 per ton of coal processed. We estimate that by selling the pyrite, the coal company could save about two-thirds of the refuse disposal cost, or about $0.10 per ton of coal. We believe that the reduction in potential air and water pollution by recovering the pyrite would be worth at least an additional $0.05 per ton of coal to the coal company.

(4) Summary of Credits to a Coal Company -- If a coal company sells an 85% pyrite feed stream to a sulfuric acid manufacturer with a 1500-TPD plant, and the current brimstone price is $40 per long ton, the acid manufacturer should be willing to pay $6.65 per ton of 85% pyrite. This pyrite price, obtained from Figure III-2, is the price that permits the acid manufacturer to make acid for the same cost (including return on investment) as when using brimstone.

Using the pyrite-removal process outlined in Figure III-1 (these pyrite and coal yields are based on Kittanning-seam experience), about 17 tons of clean coal is obtained per ton of 85% pyrite. The credit of $6.65 per ton of pyrite would thus be equal to $0.39 per ton of coal sold to the utilities.

The coal company should be able to obtain a $1.10-$1.20 premium per ton for low-sulfur coal if the purchasing utility is faced with stringent anti-pollution laws.

The last credit to the coal company would be about $0.15 per ton of coal savings, because sale of pyrite would reduce the amount of coal preparation plant refuse and its attendant problems of air and water pollution.

While the credits pertaining to pollution abatement ($1.10-$1.20 plus $0.15 per ton) are reasonably certain, the credit relating to the sale of pyrite is much more uncertain, being a function of such factors as sulfuric acid demand, the price of brimstone, competing prices for acid, location of the acid plant, and the purpose for which the pyrite-based acid is to be used. These questions are discussed later, in Sections IV and V.

On a realistic basis, therefore, the credit which might be expected by a coal company selling low-sulfur coal to utilities faced with stringent anti-pollution laws would be approximately $1.25-$1.35 per ton of low-sulfur coal plus whatever price the pyrite could command.

B. MANUFACTURE OF SULFURIC ACID FROM PYRITE

1. General Discussion

The objective of this section of the report is to determine the operating and investment costs associated with the manufacture of sulfuric acid (98%) from a less than 100% pyrite feed, which might be obtained from a single coal-preparation plant or group of plants.

The location of the precise pyrite source or sources was unknown, and detailed estimates of the beneficiation costs associated with effective removal of pyrite from coals are not available. It was therefore decided that manufacturing costs would assume pyrite on the plant site, free of any delivery charges. Further by-product credits, such as for iron calcines, were not included in the basic estimates, since chemical analyses of the calcines were unavailable and since firm customers for the calcines had not been identified. In a later section of this report, the possible credits to be expected from calcines are detailed as far as is possible.

In order to provide a wide practical range of possible operating conditions for a sulfuric acid plant based upon a pyritic feed, the following parameters were established:

Plant Capacity, Tons per Day Sulfuric Acid (98%)
250
500
1000
1500
2500

Plant Feed Composition

No.	% Pyrite	% Coal	% Gangue
2	90	5	5
4	80	7	13
6	85	10	5
8	70	10	20
10	70	15	15
12	65	23	12

Plant Type		
	I-A	Cooling tower and steam generation equipment.
	I-B	Steam generation equipment but no tower.
	II-A	Cooling tower, no steam generation equipment.
	II-B	No cooling tower, no steam generation equipment.

Investment and operating costs were then calculated for each possible combination.

Figure III-3 shows graphically the total capital investment required for pyrite plant feed compositions numbers 2 (90% pyrite, 5% coal, 5% gangue)

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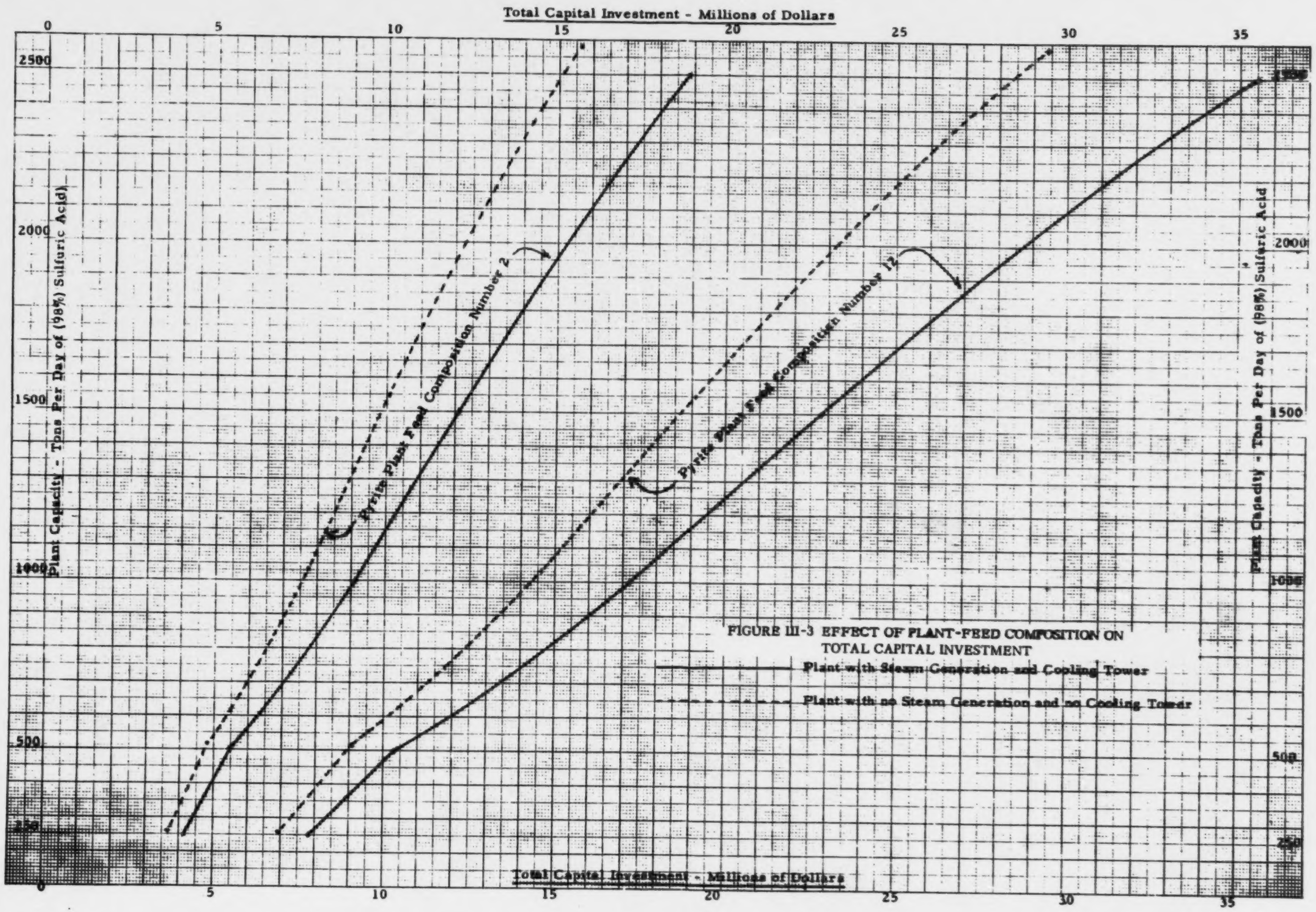

FIGURE III-3 EFFECT OF PLANT-FEED COMPOSITION ON TOTAL CAPITAL INVESTMENT

and 12 (65% pyrite, 23% coal, 12% gangue). This graph illustrates the very pronounced effect of pyrite plant feed composition on capital cost requirements.

The effect of plant capacity on capital investment costs is illustrated in Table III-6 for pyrite plant feed composition number 6 (85% pyrite, 10% coal, 5% gangue) for a plant with steam generation equipment and with a cooling tower.

TABLE III-6

EFFECT OF PLANT CAPACITY ON CAPITAL INVESTMENT COSTS

(Pyrite Plant Feed Composition No. 6
85% Pyrite, 10% Coal, 5% Gangue)

Plant Capacity (tons per day) (98% sulfuric acid)	Capital Investment Dollars per Annual Ton Capacity
250	$60.50
500	40.60
1,000	33.20
1,500	29.40
2,500	27.50

The effect of pyrite plant feed composition on capital costs is illustrated in Table III-7 for a plant capacity of 1500 tons per day of sulfuric acid (98%) and for plants both with and without steam generating equipment but with cooling towers in each case.

Total capital investments for the four different types of plants and for the six different pyrite feed compositions and for capacities from 250 to 2500 tons per day of sulfuric acid (98%) are presented in Table III-21 in the section entitled "Plant Costs and Total Capital Investment."

TABLE III-7

EFFECT OF PLANT FEED COMPOSITION ON CAPITAL INVESTMENT COSTS
(1500 tons per day sulfuric acid (98%))

Plant Feed Composition				Capital Investment Dollars per Annual Ton Capacity	
No.	% Pyrite	% Coal	% Gangue	With Steam Generation	No Steam Generation
2	90	5	5	$24.40	$20.50
4	80	7	13	27.25	22.90
6	85	10	5	29.40	24.60
8	70	10	20	31.20	26.25
10	70	15	15	36.25	30.50
12	65	23	12	46.00	38.70

Figure III-4 shows graphically the total processing cost for pyrite plant feed compositions number 2 and 12. This graph illustrates the very pronounced effect of pyrite feed composition on the in-plant processing costs. The processing costs given include the direct operating costs such as labor, water, power, etc., and the indirect operating costs such as labor overhead, taxes and insurance, plant depreciation, etc. These costs do not include the cost of the pyrite plant feed nor any shipping charges for the pyrite or the product acid; costs are based on starting with pyrite in a storage pile at the plant site and ending with product acid in storage tanks at the plant site. Finally, the processing costs shown exclude any credits such as credits for the calcines or turbine exhaust steam or any credit that might be assigned to either the pyrite roasting-acid plant operation or the coal beneficiation operation by virtue of a cleaner, lower-sulfur coal being offered for sale.

NOT REPRODUCIBLE

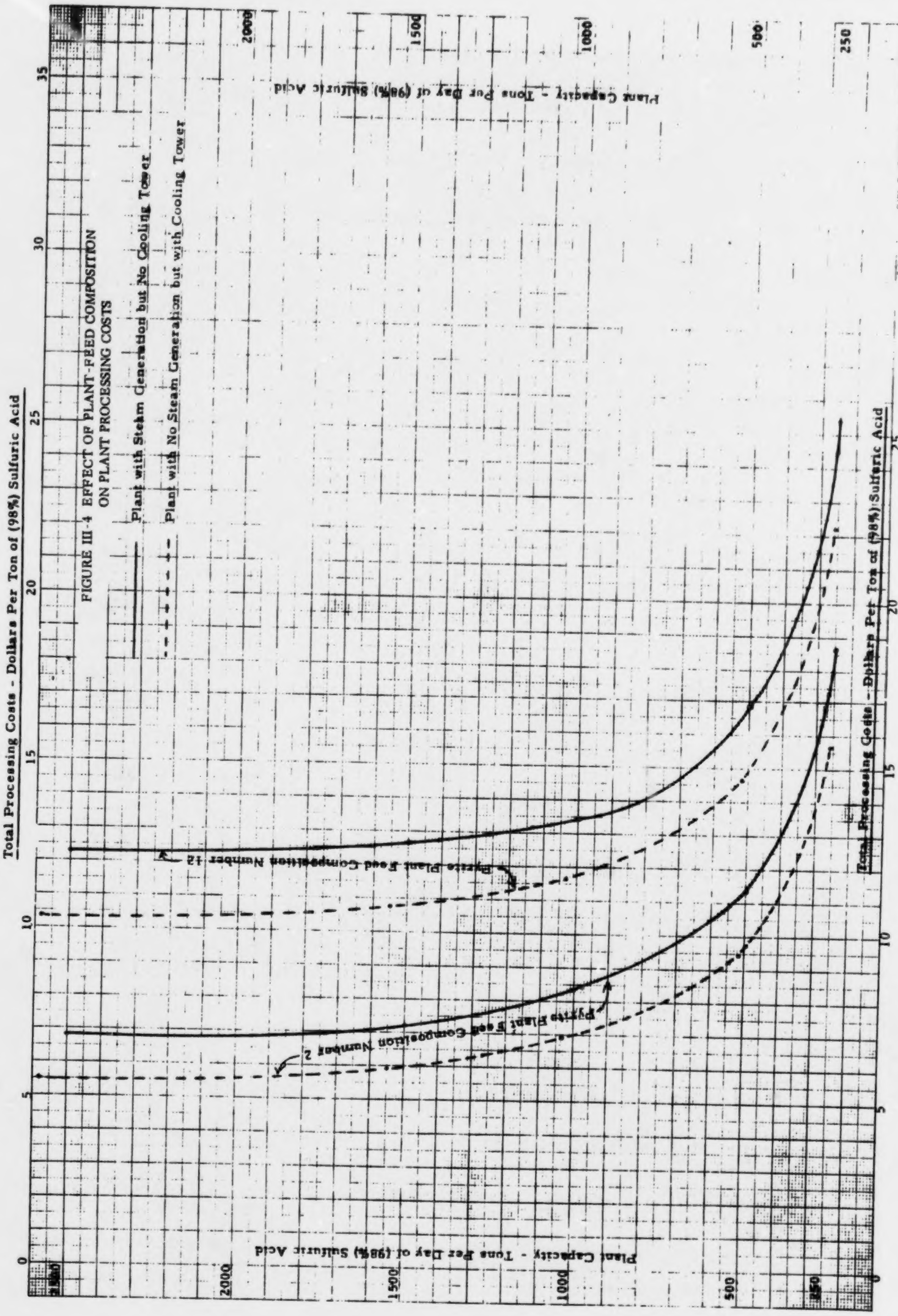

FIGURE III-4 EFFECT OF PLANT-FEED COMPOSITION ON PLANT PROCESSING COSTS

Processing costs for pyrite plant feed composition number 6 (85% pyrite, 10% coal, 5% gangue) are shown in Table III-8 for plant capacities from 250 to 2500 tons per day of (98%) sulfuric acid. These cost figures are for plants both with and without steam generating equipment but with water cooling towers in each case.

TABLE III-8

PROCESSING COSTS FOR VARIOUS PLANT CAPACITIES
(Pyrite Plant Feed Composition No. 6
85% Pyrite, 10% Coal, 5% Gangue)

Plant Capacity TPD (98%) Product Acid	Plant Processing Costs Dollars per Ton (98%) Sulfuric Acid	
	With Steam Generation	No Steam Generation
250	$19.59	$17.17
500	11.76	10.52
1,000	8.63	7.82
1,500	7.63	7.00
2,500	7.20	6.53

The effect of pyrite plant feed composition on total processing costs is illustrated in Table III-9 for a plant capacity of 1500 tons per day of (98%) sulfuric acid and for plants both with and without steam generating equipment but with water cooling towers in each case.

Figure III-5 illustrates the dramatic increase in processing costs that occurs as the ratio of pyrite to coal (e.g., sulfur to coal) decreases. Costs increase even though the amount of gangue is held constant (see data in Table III-9 for feed composition numbers 2 and 6 and for numbers 4 and 12).

TABLE III-9

EFFECT OF FEED COMPOSITION ON PROCESSING COSTS

(1500 tons per day sulfuric acid (98%))

Plant Feed Composition					Plant Processing Costs Dollars per Ton of Sulfuric Acid (98%)	
No.	% Pyrite	% Coal	% Gangue	Pyrite/ Coal Ratio	With Steam Generation	No Steam Generation
2	90	5	5	18:1	$ 6.60	$ 5.92
4	80	7	13	11:4	7.07	6.38
6	85	10	5	8.5:1	7.63	7.00
8	70	10	20	7:1	7.90	7.32
10	70	15	15	4.7:1	8.97	8.35
12	65	23	12	2.8:1	11.53	10.76

The total processing costs for the four different types of plants and for all six pyrite plant feed compositions and for plant capacities from 250 to 2500 tons per day of sulfuric acid (98%) are presented in Table III-35 in the "Operating Costs" section.

Based on the total processing costs that have been determined in this study, it would seem advisable to consider processing pyrite plant feed composition numbers 2, 4, 6, and 8. Both technically and economically, use of a pyritic material such as pyrite feed number 10 is quite questionable. Pyrite plant feed number 12 is not suitable either technically or economically. The higher the grade of pyrite plant feed, the lower the total capital investment and the lower the total processing cost. However, in selecting the preferred grade of pyrite feed, one must consider the cost of producing the various grades of

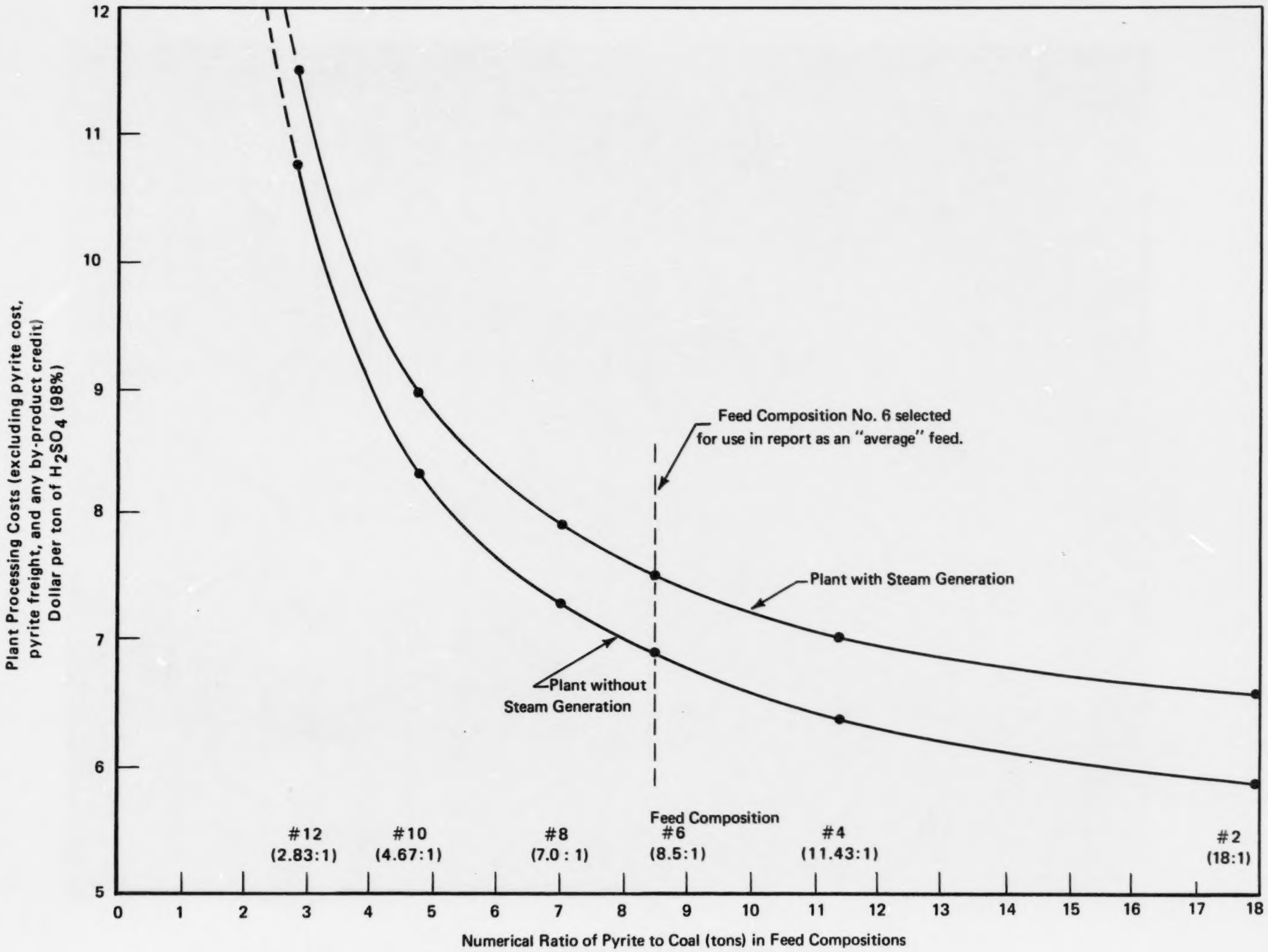

FIGURE III-5 EFFECT OF FEED COMPOSITION ON PLANT PROCESSING COSTS 1500 TON-PER-DAY SULFURIC ACID (98%)

pyrite. Also in some cases with some coals it may not be technically possible or practical to produce a pyrite material with as good a composition as pyrite plant feed composition number 2 (90% pyrite, 5% coal, 5% gangue, with a sulfur-to-carbon ratio of 13.8:1).

The larger the plant capacity, the lower the total capital investment per annual ton of capacity and the lower the total processing cost per ton of product acid. Plant capacities of less than 1000 tons per day of sulfuric acid (98%) would generally be difficult to justify economically, and plants of 1500 tons per day or more are definitely preferred from an economic standpoint.

The preference for type of plant will depend upon many interrelated factors. Where electrical power is expensive and where there is a need for low-pressure steam, a pyrite-roasting plant with steam-generating equipment should be considered. With cheap power and no use or value for low-pressure steam, the steam-generating equipment cannot be justified.

A large quantity of cooling water is required in the process for cooling the roaster exit gases and for cooling the product acid. If the cost of cooling water is $0.05 per 1000 gallons or more, an evaporative-type cooling tower to provide the necessary cooling water should be included as part of the processing plant. The total processing costs for plants with steam-generating equipment but without cooling towers are in the range of $0.60-$0.75 higher per ton of product acid than for plants with cooling towers using cooling water purchased for $0.05 per 1000 gallons. For plants without steam-generating equipment, the difference is in the range of $1.00 to $1.30 per ton of product acid. Unless the plant is located where there is a reliable, abundant, clean, inexpensive source of cooling water, an evaporative cooling tower is definitely called for. Even if an abundant source of water is available, the use of a cooling tower should be favorably considered as a means of reducing thermal pollution of the body of water along which the plant is located.

The economics of a project such as is being considered here will be improved if a market can be found for the calcines produced in roasting the pyrite. There are two possibilities to be considered as a means of obtaining a credit for the iron values in these calcines. One approach would be to further beneficiate the calcines to produce high-grade (60 - 65% Fe) pellets to sell to the steel industry for blast-furnace charge ore. This approach has been investigated in this study (see Section III C). The beneficiation process consists of FluoSolids reduction roasting followed by grinding and magnetic separation and pelletizing of the magnetic concentrate. This approach cannot be economically justified because of the relatively small tonnage of pyrite calcines involved,except perhaps for a plant with a capacity of 2500 tons per day of sulfuric acid. Even here the capital expenditure required for the beneficiation plant makes the economics look questionable.

The other,and more practical, approach would be to sell the calcines, as produced, to the steel industry as a source of iron oxide fines for their sintering machines. The economics of this approach depend upon whether or not the steel mills will use this type of material and how much they are willing to pay for it. Details concerning these two approaches are to be found in Section III C, "Calcine Utilization."

The idea of using tonnage oxygen to enrich the air used for roasting or oxidizing the pyrite-coal feed material has been studied as a possible way of reducing the processing costs. Based on the cost of tonnage oxygen as used in this study, this approach would not decrease the processing costs. Details of the study may be found in Appendix B.

In this study the high-pressure steam that is generated in the bed coils and the waste-heat boiler is used in turbine drives to power the fluidizing air blower of the roasting plant and for the SO_2 blower in the acid-plant section. Low-pressure turbine exhaust steam at 20 to 30 psig is available and might be considered as a credit to the operation. (In an integrated fertilizer manufacturing operation, a brimstone-based acid plant will produce approximately the same amount of low-pressure steam as will an acid plant using feed composition No. 6. In such a case, there is no credit as such; the two operations are merely similar regarding steam production.)

A range of possible steam values, from $0.30 to $0.70 per 1000 pounds, was used to estimate a possible credit for steam should a market be available. Table III-10 shows the amount of steam which could be produced from the four principal feed compositions by plant type IA or IB and the credits which could apply.

In general, excluding the possibility of an integrated operation, generation of low-pressure by-product steam for sale is not practiced in the United States; costs associated with such production are too high. In the situation of a pyrite-based acid plant, investment and operating costs are increased and sulfur recovery is somewhat reduced (approximately 3%). On the plus side, electric power costs are lowered, and if a cooling tower is not used, water requirements are reduced. On balance, the costs outweigh the advantages, and for this reason we have not provided for a steam credit to the operation. Each specific situation should be examined on its own merits, however, and the possibility of steam sale carefully evaluated.

TABLE III-10

POSSIBLE LOW-PRESSURE STEAM CREDITS

Feed Composition Number	Tons Steam per Ton Acid Produced (98%)	Possible Steam Credit, Dollars per Ton 98% Acid at:		
		$.30/1000 lb	$.50/1000 lb	$.70/1000 lb
2	1.0	0.60	1.00	1.40
4	1.1	0.66	1.10	1.54
6	1.2	0.72	1.20	1.68
8	1.3	0.78	1.30	1.82

A brief review was made of processes that might be considered for producing either a combination of sulfuric acid and elemental sulfur or elemental sulfur only from the pyrite-coal feed material. Detailed capital costs and processing costs were not developed for pyrite derived from coal for any of these processes. One flash smelting process, the Outokumpu process, is being used in Finland for treating pyrite and recovering in addition to the iron such other metal values as copper, zinc, lead, and silver. The sulfur is recovered as sulfuric acid and elemental sulfur, and there is considerable steam generation hich can be used for electrical power generation. This process looks quite attractive for their particular situation. Also there are two processes involving fluid-bed operations that might be considered. Preliminary economic analyses based on a high-grade (50%S) pyrite (not derived from coal) indicate total processing costs in the range of $28 to $34 per long ton of elemental sulfur. These two fluid-bed processes are still in the development stage and have not been proven either technically or economically on a commercial scale.

2. Description of Process

a. Coal Preparation and Cleaning

Although coal-preparation or -cleaning is not part of this process study per se, a brief description of it may give a better understanding of subsequent processing. Sulfur occurs in coal in two principal forms: organic sulfur (an organic part of the coal substance) and pyritic sulfur (iron sulfide, FeS_2). The organic sulfur cannot be removed by known physical processing means, and desulfurization of coals is therefore accomplished only by removal of the pyritic form of sulfur. The degree of pyrite removal from coal depends upon (1) how finely the pyrite is disseminated in the coal matrix and (2) the extent of processing to remove it.

The function or purpose of a coal-preparation or coal-cleaning plant is to remove noncarbonaceous matter from the mined coal to produce an upgraded coal and a reject or plant refuse. This plant refuse would contain such materials as shale, sandstone, clayey matter, pyrite, and bony coal. The amount and composition of the plant refuse will vary over a rather wide range from plant to plant and from coal to coal. To be economically useful the plant refuse would generally have to be retreated to produce a sulfur-rich pyrite concentrate and sulfur-poor tailings or reject. The grade or composition of the pyrite concentrate then can be expected to vary over a wide range with (1) the type of mined coal, (2) the coal preparation operation, and (3) the refuse retreatment operation.

In order to make this study as useful and meaningful as possible, processing costs and economic data for sulfuric acid production have been developed for the grades of pyrite concentrates listed in Table III-9.

b. Pyrite Roasting

Acid production from the pyrite concentrate is accomplished by first processing the pyrite through a FluoSolids roasting plant. Here the pyrite feed is subjected to an oxidizing roast which liberates the sulfur as SO_2 gas for subsequent acid manufacture. The acid plant is specifically designed to operate using sulfur dioxide gas obtained from the FluoSolids roasting plant. A general flow diagram illustrating the combined plants is in Figure III-6. It should be noted that the FluoSolids pyrite roasting and contact acid manufacturing processes are standard,proven processes that have been applied world-wide for the manufacture of sulfuric acid.

Pyrite derived from coal will naturally contain varying amounts of coal and also varying amounts of shale, sandstone, etc., or what may be

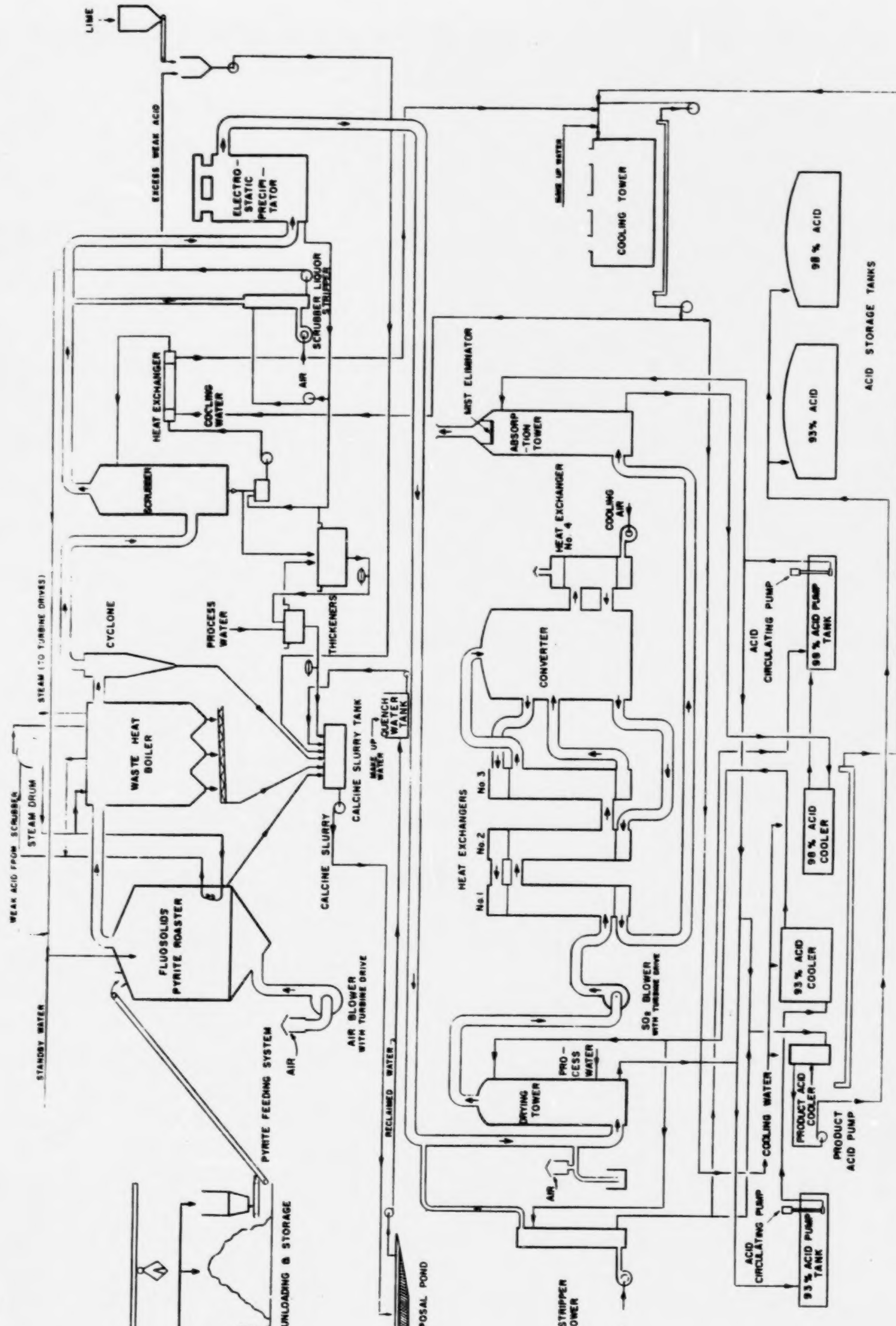

FIGURE III-6 FLOW DIAGRAM OF FLUOSOLIDS PYRITE-ROASTING/
SULFURIC-ACID PLANT
PLANT TYPE I-A

referred to as gangue or inerts. The principal reactions in the roasting or oxidation of pyrite and coal with air are shown below.

$$FeS_2 + \underbrace{2.75\,O_2 + 10.35\,N_2}_{13.1\text{ Air}} \rightarrow 0.5\,Fe_2O_3 + 2SO_2 + 10.35\,N_2$$

$$C + \underbrace{O_2 + 3.76\,N_2}_{4.76\text{ Air}} \rightarrow CO_2 + 3.76\,N_2$$

$$H_2 + \underbrace{0.5\,O_2 + 1.88\,N_2}_{2.38\text{ Air}} \rightarrow H_2O + 1.88\,N_2$$

All the above reactions are heat-generating or exothermic to such an extent that the roasting of the pyrite-coal mixture is self-sustaining at elevated temperatures, with the generation of excess heat in the FluoSolids reactor over that required to maintain the operation at the normal roasting temperature of 1650°F. This excess heat may be used to produce high-pressure steam. This is done by placing heat-absorbing steam-generating coils within the fluidized bed of the reactor to remove this excess heat and to assist in controlling the temperature of the fluid bed. Final roasting temperature control is then obtained by the addition of a small controlled amount of water or weak waste acid to the reactor. More steam production may be obtained by passing the hot exit gases from the reactor through a waste heat boiler to cool the gases to about 650°F. The steam produced is usually 450 to 590 psi and saturated or superheated if desired. Steam production as presented in this report is based on producing

500 psig saturated steam and superheating this steam to 650°F in a small superheater section in the waste heat boiler. The steam that is produced in the FluoSolids steam generating coils and in the waste heat boiler may be used to generate electrical power or used directly in the roasting and acid plant sections with steam turbine drives for the air blower for supplying air to the FluoSolids reactor and for the acid plant SO_2 blower. The exhaust steam from these turbine drives at 20 to 30 psig may be further used as an additional heat source, as, for example, in the acid evaporators of a phosphoric acid plant or for other uses. A steam-generating FluoSolids roasting plant with a waste heat boiler and bed coils is hereafter referred to as "Plant Type I."

In situations where electrical power is inexpensive and there is no use for low-pressure turbine exhaust steam, the waste heat boiler and bed coils may be eliminated. In such cases the excess heat that is generated in the reactor is removed by the direct addition of water or weak waste acid into the FluoSolids reactor. The elimination of steam-generating equipment in the roasting-plant section can be expected to reduce the capital investment requirements and the operating labor and maintenance requirements. A FluoSolids roasting plant with no steam-generation equipment is hereinafter referred to as "Plant Type II."

The type of plant to be selected for a particular situation will then depend upon the cost of electrical power and the need for and value of steam.

The partially cooled SO_2-bearing gas (650°F) from the waste heat boiler then goes to a cyclonic dust collector and then on to final gas cooling and cleaning. The gas passes through a multi-stage scrubber which removes the major portion of the fine calcine particles in the gas and cools the gas to about 105°F. This cool, wet (saturated at 105°F) gas goes to final cleaning in an electrostatic or mist precipitator, which removes the ultra fine calcine particles and SO_3 mist, before proceeding to the contact acid plant section.

The calcines leaving the reactor fluid bed, the waste heat boiler, and the cyclone dust collector consist of iron oxide (Fe_2O_3) and gangue. They may be collected dry or as a slurry in water, depending upon their final disposition. If the calcines are to be discarded, the normal procedure is to use wet cine disposal area. A portion of the water used for calcine collection and disposal may be recovered from the calcine disposal area and recycled if desired, as shown in Figure III-6. If the calcines are to be considered as a source of iron, such as for sinter-plant feed at a steel mill, they would be collected dry, cooled, and moistened with water to 3 to 5% H_2O to prevent dusting and losses in shipment. Dry storage and loading facilities for rail or barge shipment would be required. If the calcines were to be further processed to make high-grade Fe_2O_3 pellets for steel-mill blast-furnace charge ore, they would be collected dry and transferred, without cooling, to the first stage of the pellet production process. The process referred to here, a reduction, magnetic concentration, pelletizing process of the type being used by Montecatini at their Follonica, Italy plant, is discussed in Section III C.

The effluent from the gas scrubber and electrostatic precipitator contains fine calcine solids, sulfuric acid, and dissolved solids, principally iron. These effluent streams go to a thickener for liquid-solids separation. The thickened solids are pumped to the calcine quench system. The clarified liquor, a weak 10 to 20% H_2SO_4 solution, because of its dissolved iron content and other dissolved impurities, is generally not usable as sulfuric acid. However, a maximum portion of this waste acid solution is returned to the FluoSolids pyrite roaster for temperature control and the remainder, estimated to be approximately 1% of the total sulfur for Plant Type II and 3.5% for Plant Type I, is neutralized with lime and sent to the disposal area.

c. Sulfuric Acid Production

The clean, cool, water-saturated SO_2 gas is passed through the drying tower, where its moisture is absorbed by 93% sulfuric acid flowing countercurrent down through the tower. The acid leaving the bottom of the drying tower passes to the 93% acid pump tank. The 93% acid is then pumped through the 93% acid cooler and recirculated to the top of the drying tower.

The dry, clean, SO_2-bearing gas then goes to the SO_2 blower. This blower serves to draw the gas through the gas cooling, cleaning, and drying equipment (i.e., waste heat boiler, cyclone, scrubber, precipitator, and drying tower) and to force the dry, clean, cool SO_2 gas through the balance of the acid plant. After passing through a series of heat exchangers, which heat the gas to the proper temperature, it enters the upper section of the converter. In the converter the SO_2 gas, in the presence of vanadium pentoxide catalyst, reacts with oxygen in the gas to form gaseous sulfur trioxide. This reaction liberates heat, and the catalyst is, therefore, separated into multiple beds for the purpose of controlling gas temperatures by cooling between beds. The temperature of the gas entering each bed of catalyst is controlled to obtain the maximum over-all catalytic conversion of SO_2 to SO_3. The heat removed in the converter is used to preheat the incoming cool dry SO_2 gas from the drying tower.

After conversion of the SO_2 to SO_3 the gas is then passed upward through the packed absorption tower, and the SO_3 is absorbed in the 98% acid flowing countercurrent down through the tower. After SO_3 absorption, the residual gas (nitrogen, carbon dioxide, water vapor, and less than 1% SO_2) passes through a mist eliminator in the top of the tower, leaves the tower, passes upward through the plant stack and discharges into the atmosphere.

The acid leaving the bottom of the absorption tower flows through the 98% acid cooler and then into the 98% acid pump tank. The 98% acid is then circulated back to the absorption tower and pumped to the 93% acid section.

The proper acid strengths in the two sections of the acid plant, i.e., 93% acid in the drying section and 98% acid in the absorption section, is maintained by circulation of 98% acid to the 93% acid drying section where, because of water absorption from the incoming SO_2 gas, the acid is diluted; likewise, 93% acid is circulated to the 98% acid absorption section, where the acid is concentrated by virtue of SO_3 absorption. Product acid of varying strengths can be produced, and the normal practice is to produce either 93% acid or 98%

acid. Product acid strength is controlled by the addition of process water to the drying tower. The minimum grade of plant feed (pyrite concentrate) that can be used will be discussed in Section III B 3 and 4.

3. Process Data

The grade of pyrite feed has a very pronounced effect upon the pyrite roasting and acid manufacturing processes,as it effects the equipment sizing and therefore the capital costs and operating costs.

For this study the pyrite feed compositions shown in Table III-11 have been considered. These plant feeds contain three main components or constituents, namely; pyrite, coal, and gangue or inerts. The pyrite is considered to be a pure mineral, FeS_2 containing 46.5% Fe and 53.5% S. The coal portion, whose analysis will vary as a function of source, was taken to have an analysis of: 70.2% C, 5.3% H_2, 1.3% N_2, 11.3% O_2, 2.2% S and 9.7% ash, which we believe to be fairly typical of an average Pennsylvania - Illinois bituminous coal. The gangue portion, which would include shale, sandstone, clay, etc., was not given a specific chemical composition but was considered as an inert or inactive material that would not enter into the various chemical reactions in the processes.

The weight ratios of sulfur to carbon and sulfur to hydrogen have been included as they have a most important bearing on the various process requirements such as; feed-roasting requirements,air requirements, product gas volumes,and analyses and amount and composition of calcines. This is illustrated below in Table III-12,which shows pertinent process data for Fluo-Solids roasting of the various pyrite feed compositions.

TABLE III-11

	Plant Feed Composition Number					
Feed Composition (Weight % Dry)	2	4	6	8	10	12
Pyrite	90	80	85	70	70	65
Coal	5	7	10	10	15	23
Gangue (Inerts)	5	13	5	20	15	12
Total	100	100	100	100	100	100
Chemical Analyses (Weight %)						
Sulphur	48.31	42.95	45.72	37.62	37.74	35.30
Iron	41.80	37.20	39.50	32.60	32.60	30.30
Carbon	3.51	4.92	7.02	7.02	10.52	16.12
Hydrogen	0.265	0.37	0.53	0.53	0.795	1.22
Nitrogen	0.065	0.09	0.13	0.13	0.195	0.229
Oxygen	0.565	0.791	1.13	1.13	1.697	2.601
Coal Ash	0.485	0.679	0.97	0.97	1.453	2.230
Gangue (Inerts)	5.000	13.000	5.00	20.00	15.000	12.000
Total	100.000	100.000	100.00	100.00	100.000	100.000
Weight Ratio In Dry Feed						
Sulphur/Carbon	13.8	8.7	6.5	5.36	3.58	2.2
Sulphur/Hydrogen	182	116	86	71	47.5	29

TABLE III-12

Pyrite Roasting Process Data

Plant Feed Composition Number

	2		4		6		8		10		12	
[1]Plant Type	I	II	I	II	I	II	I	II	I	II	I	II
Pounds Dry Feed Required/Ton (98%) Acid	1,470	1,425	1,660	1,605	1,550	1,500	1,890	1,830	1,890	1,820	2,000	1,935
Cubic Feet of Roasting Air Required/Ton (98%) Acid	71,600	69,500	77,700	75,100	82,900	80,200	87,900	85,000	102,500	99,200	125,000	121,000
Pounds Calcines Produced/Ton (98%) Acid	960	930	1,110	1,070	970	940	1,275	1,235	1,180	1,140	1,150	1,110
Cubic Feet of Feed Oxidation Product Gases/Ton (98%) Acid	69,000	67,000	75,500	73,000	80,700	78,200	86,000	83,300	99,500	96,400	125,000	121,000
Feed Oxidation Product Gas Analyses - % by Volume												
SO_2	12.4		11.4		10.6		10.0		8.6		6.8	
CO_2	2.4		3.5		4.3		5.0		6.4		8.3	
O_2	2.0		2.0		2.0		1.9		1.9		1.9	
N_2	82.1		81.5		81.1		80.9		80.2		79.2	
H_2O	1.1		1.6		2.0		2.2		2.9		3.8	
Total	100.0		100.0		100.0		100.0		100.0		100.0	
Net Steam Production (500 psig 650° F)												
Tons Steam/Ton (98%) Acid	1.0	0	1.1	0	1.2	0	1.3	0	1.6	0	2.1	0
Tons Steam/Ton Dry Feed	1.4	0	1.35	0	1.6	0	1.35	0	1.7	0	2.1	0

[1] Plant Type I is with Waste Heat Boiler and Steam Generating coils in the fluid bed to give maximum steam production, and process data is based on 90% overall recovery of sulphur in the pyrite feed as product acid.

Plant Type II does not have a waste heat boiler or steam generating bed coils (no steam generation), and process data is based on 93% overall recovery of sulphur in the pyrite feed as product acid.

Details concerning sulphur recovery are presented in Table 13.

Recovery of sulfur in the pyrite feed as product acid depends upon a number of factors; the principal ones are pyrite feed composition, operating conditions, and the type of plant. If the pyrite feed contains alkali components, such as CaO and MgO, these components will form $CaSO_4$ and $MgSO_4$ to tie up some of the sulfur in the feed. Complete oxidation of the sulfide sulfur in the pyrite feed cannot be expected, and there will be a small amount of residual sulfide sulfur retained in the hematite calcines. The amount of sulfur retained in the calcines will have a significant bearing on the value of the calcines if they are to be used as a sinter strand feed.

The amount of residual sulfide sulfur is a function of roasting conditions such as: roasting temperature, amount of excess air used for oxidizing the pyrite and coal, pyrite feed particle size, and calcine residence time at roasting temperature. Also, the type of plant will have a bearing on overall sulfur recovery. In Plant Type I with a waste heat boiler, the hot exit gases from the FluoSolids reactor are cooled comparatively slowly through the temperature range from 1650 to 650°F in the presence of Fe_2O_3 calcine particles. This slow cooling through this temperature range promotes the conversion of SO_2 to SO_3, particularly in the presence of Fe_2O_3, which acts as a catalyst for the reaction. The SO_3 that is formed in cooling the roaster gases constitutes a loss of sulfur as (1) sulfate sulfur in the calcines due to reaction between the SO_3 and the iron oxides in the calcines, and (2) as sulfuric acid due to necessary removal of the SO_3 in the gas scrubber and electrostatic (mist) precipitator, with this acid occurring in the effluent streams from the scrubber and precipitator as a weak acid along with the fine calcine particles.

Furthermore, with Plant Type I, the bulk of the excess heat of reaction from the oxidation of the pyrite and coal in the FluoSolids reactor is removed by steam-generating bed coils. Therefore, only a small amount (roughly 25 to 35%) of this weak acid from the gas scrubber and precipitator can be recycled to the roaster for final roasting temperature control.

With Plant Type II (no waste heat boiler) the quenching of hot roaster gases in the gas scrubber reduces SO_3 formation. Also in Plant Type II all the excess heat of reaction from pyrite and coal oxidation may be removed by recycling the bulk (roughly 75 to 85%) of this weak acid to the reactor for roaster temperature control, thereby reducing the amount of weak acid that need be neutralized and discarded.

The other principal source of sulfur loss is in incomplete conversion of SO_2 occurring in the acid plant stack gases along with a very minor amount of acid mist that is not collected in the mist eliminator at the top of the absorbing tower. The efficiency of conversion of SO_2 to SO_3 in the contact acid plant will depend upon the number of stages in the convertor, the amount and condition of the vanadium pentoxide catalyst in each stage, incoming gas composition (particularly the SO_2 - O_2 ratio), and the operating temperatures in the various stages of conversion and other factors.

It can thus be seen that because of the many process variables connected with the roasting and acid-plant sections of the plant and the almost infinite variety of combinations that could occur, sulfur recovery can vary significantly. With this in mind, Table III-13 was prepared as a general guide

TABLE III-13

Sulphur Distribution and Recovery

Sulphur In	Pounds of Sulphur/Ton (98%) Acid		% of Total Sulphur In	
	Plant Type I	Plant Type II	Plant Type I	Plant Type II
From Pyrite Feed	710	690	100.0%	100.0%

Sulphur Out	Pounds of Sulphur/Ton (98%) Acid		% of Total Sulphur Out	
	Plant Type I	Plant Type II	Plant Type I	Plant Type II
1. In calcines (as sulphide and sulphate sulphur)	16 to 20	12 to 16	± 2.5%	± 2.0%
2. In gas scrubbing and cooling effluent (as weak acid)	23 to 27	5 to 9	± 3.5%	± 1.0%
3. Acid plant losses (conversion and others)	± 28	± 28	± 4.0%	± 4.0%
Total Losses	67 to 75	45 to 53	± 10.0%	± 7.0%
4. Overall sulphur recovery as (98%) product acid	640	640	± 90%	± 93%

Plant Type I has a waste heat boiler and steam generation coils in the fluid bed.

Plant Type II has no waste heat boiler or steam generation coils.

to the overall sulfur recovery to be expected from either of the two basic plant types being considered in this report. It is at once apparent that process data, capital costs and operating costs are directly and significantly affected by the choice of plant.

The sulfur content of calcines from Plant Type I can be calculated from the figures presented in Table III-9 to range from a low of about 1.2% to a high of about 2.0% total sulfur and for Plant Type II about 1% to 1.7% total sulfur, depending upon the pyrite feed composition and other factors as discussed previously.

The hot, dirty SO_2 gas from the pyrite roasters must be cooled and cleaned to remove all entrained calcines and SO_3 before the gases go to the drying tower of the acid plant proper. Dust would contaminate the product acid; and SO_3 would form H_2SO_4 mist which would condense and then corrode mild-steel acid-plant equipment. Some mist would pass through the plant completely and would result in an intolerable-quality plant-gas effluent.

For Plant Type II the bulk of the excess heat of reaction from oxidation of the pyrite and coal is removed by steam-generating bed coils in the reactor, and the reactor exit gases are partially cooled in a waste heat boiler. With this type plant the heat to be removed in the gas scrubber is minimized and the cooling water requirement for the gas scrubber is also minimized. With Plant Type II, heat to be removed in the gas scrubber is at a maximum and there is no waste heat boiler to partially cool the roaster exit gases. Also, the excess heat of reaction from oxidation of the pyrite and coal in the roaster must also be removed by the gas scrubber. Although water or weak acid is introduced into the reactor to remove all excess heat and control the roasting temperature, this heat load from the reactor is in essence transferred to the gas scrubber as the water vapor that is formed in the reactor from evaporation of the water or weak acid and must be condensed in the gas scrubber. Pertinent process data for the gas scrubbing (cooling) portion of the plant and for the contact acid plant are presented in Table III-14.

The amount and composition of the iron oxide calcines will naturally depend upon the composition of the pyrite feed to the plant. The following Table III-15 gives data on the amount and approximate composition of the calcines that are to be expected for the various pyrite feed compositions.

The size of the iron oxide calcines will naturally depend upon the size of the pyrite feed and the amount of breakdown or decrepitation of the pyrite in roasting, which may be as little as 1 mesh (Tyler) or perhaps as much as 5 or 6 meshes.

4. Effect of Pyrite Feed Composition on Process Requirements

As has been shown in Section III B 3, "Process Data," the pyrite feed composition has a very pronounced effect on almost all of the process requirements in both the pyrite roasting section and in the contact acid plant section.

As the grade of pyrite feed decreases (less pyrite-more coal), the process requirements are affected as follows:

TABLE III-14

Gas Scrubbing and Cooling Process Data

Plant Feed Composition Number

Plant Type[1]	2 I	2 II	4 I	4 II	6 I	6 II	8 I	8 II	10 I	10 II	12 I	12 II
Total Exit Gas From FluoSolids Reactor												
Cubic feet (at temperature and pressure) per ton of (98%) acid	304,300	368,000	333,500	405,000	357,600	438,000	381,200	467,000	441,000	547,000	553,000	705,000
Analyses of Wet Exit Gas from Roasting % by Volume												
SO_2	11.2	9.2	10.3	8.5	9.5	7.8	8.5	7.3	7.7	6.2	6.1	4.8
CO_2	2.2	1.8	3.1	2.6	3.9	3.2	4.5	3.6	5.8	4.6	7.5	5.9
O_2	1.8	1.5	1.8	1.5	1.8	1.4	1.7	1.4	1.7	1.4	1.7	1.3
N_2	74.1	61.4	73.4	60.4	73.1	59.4	73.0	59.5	72.0	57.8	71.0	55.8
H_2O	10.7	26.1	11.4	27.0	11.7	28.2	12.3	28.2	12.8	30.0	13.7	32.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Gas to contact acid plant												
Cubic feet (at temperature and pressure) per ton of (98%) acid	77,300		86,700		91,700		97,200		111,000		139,000	
Analyses of Gas (at 105° F and 14.7 psia) % by Volume												
SO_2	11.5		10.8		10.1		9.5		8.2		6.6	
CO_2	2.2		3.3		4.1		4.7		6.1		8.0	
O_2	1.8		1.8		1.8		1.8		1.8		1.8	
N_2	77.0		76.6		76.5		76.5		76.4		76.1	
H_2O	7.5		7.5		7.5		7.5		7.5		7.5	
Total	100.0		100.0		100.0		100.0		100.0		100.0	

[1] Plant Type I has a waste heat boiler and steam generating bed coils in the reactor for maximum steam production.

Plant Type II has no waste heat boiler and no bed coils (no steam generation)

TABLE III-15

Calcine Characteristics and Amount

Pyrite Plant Feed Composition Number

Pyrite Feed Composition (Weight % Dry)	2		4		6		8		10		12	
Pyrite	90		80		85		70		70		66	
Coal	5		7		10		10		15		23	
Inerts	5		13		10		20		15		12	
Plant Type →	I	II	I	II	I	II	I	II	I	II	I	II
Pounds Pyrite Feed/Ton (98%) Acid	1470	1425	1660	1605	1550	1500	1890	1830	1880	1820	2000	1935
Pounds Calcine/Ton (98%) Acid	960	930	1110	1070	970	940	1275	1235	1180	1140	1150	1110
Approximate Calcine Composition												
% Hematite (Fe_2O_3)	92		79.7		90.5		68.9		74.0		76.0	
% Fe	64.3		55.8		63.4		48.2		52.0		53.2	
% Inerts (Gangue & Coal Ash)	8		20.3		9.5		31.1		26.0		24.0	
Approximate % Total Sulphur	±1.8	±1.5	±1.6	±1.3	±1.8	±1.5	±1.4	±1.1	±1.5	±1.2	±1.5	±1.2

Plant Type I has a waste heat boiler and steam generation coils in the fluid bed.

Plant Type II has no waste heat boiler or steam generation coils.

(1) Amount of pyrite feed per ton of product acid increases;

(2) Volume of air for roasting per ton of product acid increases;

(3) Volume of product gases per ton of product acid increases in all sections of the plant;

(4) SO_2 gas strength or percentage decreases in the product gas with increased CO_2 and H_2O from coal oxidation; and

(5) Steam generation per ton of product acid increases.

It is the pyrite:coal ratio or, alternatively, the sulfur:carbon and sulfur:hydrogen ratio in the plant feed that has the major effect upon process requirements. The amount of inerts or gangue in the feed has a very minor effect upon the process requirements, in that the inert material or gangue essentially does not enter into the chemistry or chemical reactions of the roasting process. The only effect the amount of inerts has is in respect to the amount of feed required and the amount of calcines produced per ton of product acid, as shown in Table III-16.

From a process standpoint the amount of gangue or inerts in the pyrite feed has a very minor effect upon the FluoSolids pyrite roaster heat balance. The calcines exit the FluoSolids pyrite roaster at operating temperature (1650°F), bearing sensible heat. As the amount of calcines per ton of feed varies, the roaster heat balance is affected. However, since the amount of calcines per ton of feed varies less than 20%, and since the sensible heat in the calcines at operating temperature represents only about 10% of the total heat generated in the roaster by the oxidation of the pyrite and coal, the effect

TABLE III-16

EFFECT OF GANGUE ON PROCESS REQUIREMENTS

Plant Feed Composition Number	2	6	4	12	10	8
% Pyrite	90	85	80	65	70	70
% Coal	5	10	7	23	15	10
% Gangue (Inerts)	5	5	13	12	15	20
Pyrite:Gangue Ratio	18	17	6.15	5.4	4.66	3.5
Pounds Feed/Ton Acid (Plant Type I)	1470	1550	1660	2000	1880	1890
Pounds Calcines/Ton Acid (Plant Type I)	960	970	1110	1150	1180	1275
Feed:Calcines Ratio	1.53	1.6	1.49	1.74	1.59	1.48
% Fe in Calcines	64.3	63.4	55.8	53.2	52.0	48.2

on the heat balance by the amount of calcines is quite minor. It is important, however, to minimize the amount of gangue or inerts in the pyrite feed from the standpoint of shipping and handling the pyrite feed and from the standpoint of the amount and composition of the calcines.

To understand the effect of feed composition on processing cost, one must consider several process requirements. For the pyrite-roasting section, the process requirements that are affected fall into the category of gas volumes, and heat generation and/or extraction. For the contact acid section, the process requirements that are affected are in the category of gas volumes, gas composition, water balance, and heat generation or heat transfer.

One way to illustrate the effect of pyrite feed composition is to consider a FluoSolids pyrite roasting plant and a contact acid plant which is designed to handle pyrite plant feed composition number 2 and then to consider the effects of processing any one of the lower grade pyrite feeds in this same plant. Table III-17 illustrates the effect of pyrite feed composition on the various process factors or requirements. In this table absolute values have not been used, but a value of 1 or unity has been assigned to the process factors that apply to pyrite feed composition number 2; values of more or less than 1 represent an increase or decrease, respectively, in the specific process factor as shown for the other 5 pyrite feed grades that have been included in this study. These process factors are expressed in terms of, or in relation to, a ton of 98% product acid as being the most meaningful way of considering these process requirements.

In Table III-17, the capacity factors are simply the reciprocal of the average process factors. Examples of how this table should be used to show the effect of pyrite feed composition on process requirements and therefore plant capacity are presented below.

- Example 1 (Pyrite Roasting) -- A pyrite roasting plant is designed for pyrite feed No. 2 to produce SO_2 gas to supply a contact acid plant with a design capacity of 500 tons per day of 98% sulfuric acid. If pyrite feed composition No. 6 were processed in this pyrite roasting plant, the SO_2 gas production would be sufficient

TABLE III-17

Process Factors V.S. Pyrite Plant Feed Composition

Pyrite Plant Feed Composition

	2		4		6		8		10		12	
Feed Composition												
% Pyrite	90		80		85		70		70		65	
% Coal	5		7		10		10		15		23	
% Inerts	5		13		5		20		15		12	
Sulphur Carbon Ratio	13.8		8.7		6.5		5.36		3.58		2.2	
Sulphur Hydrogen Ratio	182		116		86		71		47.5		29	
FluoSolids Pyrite Roasting												
Plant Type	I	II	I	II	I	II	I	II	I	II	I	II
Process Factors (Per Ton of Product Acid)												
1. Volume of Feed Oxidation Product Gas	1.0	1.0	1.09	1.09	1.17	1.17	1.24	1.24	1.44	1.44	1.81	1.81
2. Volume of Total Roaster Exit Gas	1.0	1.0	1.10	1.10	1.17	1.19	1.25	1.27	1.44	1.49	1.82	1.92
3. Heat Removal by Steam Generating Bed Coils	1.0	---	1.13	---	1.31	---	1.35	---	1.74	---	2.42	---
4. Heat Removal in Waste Heat Boiler	1.0	---	1.07	---	1.13	---	1.22	---	1.40	---	1.74	---
5. Heat Removal in Gas Scrubber	1.0	1.0	1.16	1.13	1.26	1.27	1.43	1.36	1.61	1.66	2.08	2.23
Average of All Process Factors	1.0	1.0	1.11	1.11	1.21	1.21	1.30	1.29	1.53	1.53	1.97	1.99
(1) FluoSolids Roasting Capacity Factors	1.0	1.0	0.9	0.9	0.827	0.827	0.77	0.775	0.654	0.654	0.508	0.502
Contact Acid Plant												
Process Factors (Per Ton of Product Acid)												
Volume of Wet Cool Gas to Acid Plant	1.0		1.12		1.19		1.26		1.44		1.80	
(1) Acid Plant Capacity Factors	1.0		0.893		0.84		0.795		0.695		0.555	
Combined FluoSolids Pyrite Roasting and Contact Acid Plant												
(1) Capacity Factors	1.0		0.897		0.833		0.783		0.673		0.53	

(1) Capacity Factor = $\frac{1}{\text{Process Factor}}$

Plant Type I has a waste heat boiler and steam generating coils in the fluid bed.

Plant Type II has no waste heat boiler or steam generating coils.

for the production of only 500 x 0.827 = 413 tons per day of 98% product acid. Similarly, with pyrite feed composition No. 12 the acid production would be roughly 254 tons per day for Plant Type I or 251 tons per day for Plant Type II.

- Example 2 (Pyrite Roasting) -- A pyrite roasting plant designed to produce sufficient SO_2 from feed composition No. 2 to supply a 1000 tons per day acid plant would be of a certain size. If feed composition No. 8 were used, the pyrite-roasting plant would have to be roughly 30% larger. With feed composition No. 12 the roasting plant size would be doubled. A single roasting line using feed composition No. 2 is equivalent to two identical roasting lines using feed composition No. 12.
- Example 3 (Contact Acid Plant) -- A contact acid plant is designed to handle SO_2 gas produced from feed composition No. 2 and to produce 1000 tons per day of 98% product acid. If this plant had to handle SO_2 gas produced from feed composition No. 6, its capacity would be reduced to roughly 840 tons per day of product acid. With SO_2 from pyrite feed No. 12, the acid plant capacity would be about 555 tons per day of 98% acid.

- Example 4 (Contact Acid Plant)--A 1000 TPD 98% acid contact acid plant designed to handle SO_2 gas produced by roasting feed composition No. 2 would be of a certain size. If feed composition No. 6 were used in the roasting plant the contact acid plant would have to be approximately 19% larger. With feed composition No. 12, the acid plant size would be 80% larger.

All the preceding examples assume that there would be no technical or theoretical process limitations for the six different grades of pyrite feeds that have been included in this study. Actually this is not the case. For pyrite roasting, the capacity of a FluoSolids reactor is a function of the reactor diameter and the superficial gas velocity or space velocity through the fluid bed. As the grade of pyrite feed decreases (less pyrite, more coal) the feed-oxidation product gas volume increases per unit of SO_2 or per unit of sulfuric acid. As the gas velocity or space velocity can be expected to be essentially the same for all six grades of pyrite feed, the reactor size (diameter) increases as the feed grade decreases. As the diameter of the reactor is increased, the roasting efficiency or thoroughness of complete oxidation of the pyrite and coal will decrease, all other factors remaining constant. This decrease in roasting efficiency can be compensated for by increasing the number of pyrite feed introduction points and/or by increasing the fluid-bed depth. Increasing the fluid-bed depth results in more power being required to force the fluidizing air through the deeper fluid bed.

Increasing the number of feed introduction points increases the amount of feeding equipment and feed control instrumentation,which naturally adds to the cost of the plant.

Another factor is in connection with the steam-generating bed coils for Plant Type I. There are several different coil designs and coil arrangements that can be and have been used in fluid bed pyrite roasters to generate steam. There is, however, a common limitation that applies to all these designs and arrangements. This limitation has to do with supporting the coils in the fluid bed where they are subjected to multi-directional forces imparted to the coils by the action of the fluid bed. Because of this coil support requirement, the distance to which the coils can be inserted into the fluid bed is limited. Horizontal pipes extending across the entire fluid bed are limited to reactors up to about 20 feet in diameter and require support structures located in the fluid bed proper. Bayonet or hairpin-type coils supported from the reactor side walls are limited to about 10 feet insertion into the fluid bed. Also, any coil design or arrangement that extends into the fluid bed must be such that the coils do not materially restrict the movement and circulation of solids in the fluid bed. Coils may be placed around the periphery along the vertical side walls of the reactor. This area, however, is limited and decreases with increasing reactor diameter (i.e., decreases with increasing reactor capacity) as illustrated in Table III-18.

In the contact acid-manufacturing process, two technical or theoretical process limitations must be considered when producing acid from

TABLE III-18

FLUID-BED REACTOR DIAMETER/CAPACITY RELATIONSHIPS

Reactor Diameter (ft)	20	25	30	35
Reactor Circumference (ft)	63	78.5	94.3	110
Reactor Cross Section Area (sq ft)	314	490	706	963
Reactor Capacity Factor	1	1.56	2.25	3.06
Circumference/Area Ratio (ft/sq ft)	0.2	0.16	0.133	0.114
Circumference/Reactor Capacity Ratio	63	50	42	36

SO_2 derived from a pyrite-roasting operation. These limitations are in connection with the water balance and the heat balance within the acid plant. As has been discussed previously, the hot, dirty, SO_2-bearing gas from the roaster must be cleaned and cooled to remove all traces of calcine solids and acid mist to insure a clean acid product and to prevent corrosion problems in the mild-steel acid-plant equipment. This gas cleaning is accomplished by removing the bulk of the suspended solids in a cyclone dust-collector, followed by scrubbing the gases with water, generally with a multiple-stage wet gas scrubber or packed-tower scrubber, or in some cases by a separate gas cooler followed by a high-efficiency electrostatic mist precipitator for final removal of acid mist and ultrafine suspended solids. The clean, cool SO_2 gas then leaves the electrostatic mist precipitator saturated with water vapor at the mist precipitator exit gas temperature. This water vapor is a part of the water required to react with the SO_3 to form H_2SO_4 as represented by the equation $SO_3 + H_2O \rightarrow H_2SO_4$. Since the SO_2 gas from the roasting section contains only a small amount (± 2% by volume) of oxygen, additional oxygen must be added to the SO_2 gas stream to supply the oxygen required to oxidize the SO_2 to SO_3 as represented by the equation $SO_2 + 1/2\ O_2 \rightarrow SO_3$. An overall equation for producing H_2SO_4 from SO_2, O_2 and H_2O may be written $SO_2 + 1/2\ O_2 + H_2O \rightarrow H_2SO_4$. This oxygen for SO_2 oxidation in the convertor is added in the form of air referred to as secondary air. Although the stoichiometric oxygen requirement for the reaction

$SO_2 + 1/2\ O_2 \rightarrow SO_3$ is 1/2 volume oxygen for every 1 volume of sulfur dioxide, an excess of secondary air is added to provide in the range of 1.2 to 1.4 volumes of oxygen per 1 volume of SO_2 in the gas leaving the drying tower and going to the first stage of the convertor. This excess oxygen is necessary to compensate for imperfect mixing of the gas streams and to insure maximum conversion of the SO_2 to SO_3 . This secondary air also brings water in the form of water vapor into the acid plant and provides a portion of the water required for the production of H_2SO_4. The amount of water introduced with the secondary air is a function of SO_2/O_2 ratio and of the temperature and humidity of the secondary air.

As the concentration of SO_2 in the roaster gases decreases with decreasing pyrite feed grade, an ever-increasing amount of water per unit volume of SO_2 or of H_2SO_4 is introduced into the acid plant. At some point along the line of decreasing pyrite feed composition (less pyrite, more coal) it becomes no longer possible to make a concentrated 98% H_2SO_4 product acid in a commercial acid plant. The four process factors that influence the water balance are: (1) concentration of SO_2 in the pyrite roaster gases, (2) temperature of the clean, cool SO_2 gas leaving the electrostatic mist precipitator, (3) the volume of secondary air used to supply oxygen for SO_2 oxidation (i.e., SO_2/O_2 ratio), and (4) temperature and humidity of secondary air. Table III-19 has been prepared for the six different pyrite feed compositions based on the following conditions for these four process factors:

TABLE III-19

Contact Acid Plant Water Balance Process Data

	Pyrite Plant Feed Composition Number					
	2	4	6	8	10	12
Analyses of Pyrite Roaster Gases (Leaving electrostatic precipitator at 105°F) % by Volume						
SO_2	11.5	10.8	10.1	9.5	8.2	6.6
CO_2	2.2	3.3	4.1	4.7	6.1	8.0
O_2	1.8	1.8	1.8	1.8	1.8	1.8
N_2	77.0	76.6	76.5	76.5	76.4	76.1
H_2O	7.5	7.5	7.5	7.5	7.5	7.5
Total	100.0	100.0	100.0	100.0	100.0	100.0
Secondary Air Requirement (For 1.3 O_2 for 1 SO_2)						
Volumes Secondary Air/100 Volumes Roaster Gases	62.9	58.3	54.1	50.3	42.1	32.2
Volumes H_2O Vapor in Secondary Air (at 80°F & 90% RH)	2.02	1.87	1.73	1.61	1.35	1.03
Volumes H_2O vapor in Roaster Gases	7.5	7.5	7.5	7.5	7.5	7.5
Total Volumes H_2O Vapor	9.52	9.37	9.23	9.11	8.85	8.53
Volumes SO_2 in Roaster Gases	11.5	10.8	10.1	9.5	8.2	6.6
Volumes H_2O/Volume SO_2 (In total gases to drying tower)	0.83	0.87	0.91	0.96	1.08	1.29
Volumes H_2O/Volume SO_2 for 98% H_2SO_4	1.111	1.111	1.111	1.111	1.111	1.111
For 98% H_2SO_4 Production % of total water required supplied by gases	75%	78.4%	81.9%	86.5%	97.0%	116.0%
Volumes H_2O/volume SO_2 for 93% H_2SO_4	1.41	1.41	1.41	1.41	1.41	1.41
For 93% H_2SO_4 Production % of Total water required supplied by gases	59%	61.8%	64.5%	68.0%	76.7%	91.5%

(1) SO_2 in roaster gas a function of pyrite feed grade;

(2) Clean,cool gas leaves electrostatic mist precipitator at 105° F;

(3) SO_2/O_2 ratio of 1.3 O_2 to 1 SO_2; and

(4) Secondary air at 80° F and 90% relative humidity.

In order to maintain control of the product acid strength it is considered necessary to limit the amount of water introduced to the acid plant in the gas streams (clean,cool SO_2 roaster gas and secondary air) to a maximum of about 90% of the total water requirement, with the remaining 10% being added as process water to allow for normal variations in the four process variables that affect acid strength. Referring to Table III-19 and from a water balance standpoint only, pyrite feed grades 2 through 8 would be suitable for making 98% acid and pyrite feed compositions 10 and 12 could not be used. For 93% acid all feed grades except number 12 could be used as far as the water balance is concerned.

The conditions used in illustrating the above acid-plant water balance might be altered to improve the situation. One might consider cooling the roaster gas to some temperature less than 105°F. This would require larger and more expensive gas cooling equipment and additional cooling water. One might consider reducing the O_2/SO_2 ratio by reducing the amount of secondary air. This would lead to decreased conversion of SO_2 to SO_3 with resultant loss of sulfur values and increased SO_2 concentration in the acid plant stack gases. Dehumidification of the secondary air might be considered, but this would lead to additional capital and operating expenses which in all likelihood could not be justified.

The other technical consideration in the acid plant concerns the gas strength and heat balance around the convertor - heat exchanger section of the acid plant. The dry gas leaving the drying tower and going to the convertor-heat exchanger section of the acid plant would have an analysis as shown in Table III-20. These analyses are based on the secondary air additions as presented in Table III-19, i.e., a ratio of 1.3 O_2 to 1.0 SO_2 .

TABLE III-20

ANALYSIS OF GAS TO CONVERTER

	Pyrite Plant Feed Composition Number					
Gas Analyses-% by Volume	2	4	6	8	10	12
SO_2	7.4	7.2	6.9	6.6	6.1	5.3
CO_2	1.4	2.2	2.8	3.3	4.5	6.4
O_2	9.7	9.3	9.0	8.6	7.9	6.9
N_2	81.5	81.3	81.3	81.5	81.5	81.4
Total	100.0	100.0	100.0	100.0	100.0	100.0

The heat required to maintain the convertor at the proper temperature for conversion or oxidation of the SO_2 to SO_3 is supplied by the exothermic heat of reaction of the oxidation reaction itself:

$$SO_2 + 1/2\ O_2 \rightarrow SO_3 \qquad (23.49\ \text{Kcal})$$

Referring to the gas analyses shown in Table III-20 above, for plant feed composition No. 2, 7.4 volumes of SO_2 are oxidized to provide heat for every 100 volumes of incoming gas. For feed compositions No. 6 and 12, 6.9 and 5.3 volumes respectively of SO_2 are oxidized to provide heat for every 100 volumes of incoming gas. Without going into any heat balance calculations, it is quite obvious that somewhere along the line of decreasing SO_2 concentration (i.e. decreasing pyrite plant feed grade) there will be insufficient heat generated in the converter to maintain the conversion reaction $SO_2 + 1/2\ O_2 \rightarrow SO_3$ and the fire, so to speak, will go out. This decreasing SO_2 concentration can be compensated for, up to a point, by providing more heat exchange surface (i.e., larger heat exchangers) and by decreasing heat losses by radiation (i.e., more and better insulation). There is, of course, the added complication that with decreasing SO_2 concentration the gas volume per unit of product acid increases, which in and by itself increases the size of the converter and heat exchangers that are required to handle the weaker gases. Indications are that pyrite plant-feed composition Nos. 2 through 8 could be handled with reasonable increases in the heat exchange surfaces and improved insulation. Operation with pyrite feeds of lower grade than No. 8 would be both technically and economically questionable. As an alternative to increased heat exchange surface and improved insulation, an additional heat exchanger could be placed between the SO_2 blower and No. 1 heat exchanger; heat would be supplied by passing hot combustion gases, produced by burning oil or gas, through this heat exchanger. This would require, in addition to an alloy steel heat exchanger, a fuel combustion furnace and of course the added operating expense of oil or natural gas. This fuel-fired heat exchanger should be considered as an alternate or an adjunct to increased heat exchanger surface and improved insulation for pyrite plant feed composition Nos. 2 through 8, and not as a technical or economical solution for pyrite feeds of lower grade than No. 8.

Taking into consideration the technical or theoretical process limitations as discussed above, the process factors and capacity factors as presented in Table III-17 should be considered as reasonably practical for the contact acid-manufacturing process for pyrite feed composition Nos. 2 through 8. For feed grade No. 10 these factors are not too practical, and for feed grade No. 12 the factors should be considered as a rough order of magnitude only. From a strictly practical standpoint, utilization of pyrite plant-feed compositions of a lower grade than No. 8 would be uneconomical.

5. Plant Costs and Total Capital Investment

The capital cost requirements for the pyrite-roasting contact acid plant presented in this report were prepared on the basis that a complete plant would be built from the ground up on a virgin site. Even in a sitation where the pyrite-roasting acid plant may be located adjacent to an existing chemical, metallurgical, or other processing or manufacturing facility, any process-industry project, to be sound, must be able to support its fair share of the capital investment in other than process facilities.

The battery-limit plant costs were determined by individual cost estimates for daily production capacities of 250, 500, 1000, 1500 and 2500 tons per day of 98% acid. These estimates included all process equipment erected and including the following items:

(1) Calcine disposal and neutralized waste acid disposal equipment;[1]

(2) Liming station for neutralization of waste acid;

(3) Boiler-feed water-treatment equipment (for Plant Type I);

(4) Motor-control center, including switch gear and starters;

(5) Open (on the ground) storage for 1 month's supply of pyrite feed;

(6) Storage for 7 days' production of acid in two or more tanks;

(7) Operating-control room and such other housing as required to protect such non-weatherproof equipment as instruments, motor-control center, etc. that are a part of the process facilities; and

(8) Water-cooling tower with air-circulation fans and water pumps (for Plant Type IA and IIA).

For a complete plant, certain plant auxiliaries of the general category of utilities and service facilities are required. These are commonly referred to as offsite facilities. For this study total plant cost was determined by adding to the battery limit cost 18% for offsites for Plant Type I and 20% for offsites for Plant Type II. Offsite facilities would include:

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[1] For the purposes of this report, the investment and operating costs of calcium disposal facilities were presumed to be the same as those which would be required if the calcines were sold as a sinter strand feed material.

(1) Plant land, including pyrite and acid storage and calcine disposal;

(2) Buildings, including

- Office building, cafeteria and lab (including furniture),
- Warehouse for spare parts and maintenance supplies,
- Maintenance shop with equipment and vehicle garage,
- Change house and guard house;

(3) Power substation and power distribution;

(4) Water distribution, including drains and sewers;

(5) Roads, parking lot, and trackage;

(6) Fire protection; and

(7) Fencing, yard lighting and telephones.

In addition to these offsite facilities there are certain other costs involved having to do with the construction of the total plant and in the starting up of the plant. For this study, the total capital investment was determined by adding 11% of the total plant cost for these so-called "construction and startup costs." The latter include:

(1) Interest on construction monies;

(2) Sales taxes;

(3) Insurance coverage during construction and startup;

(4) Debt issue loan;

(5) Organizational expenses;

(6) Startup costs;

(7) Training of personnel;

(8) Permit acquisition costs; and

(9) Plant data books and plant operating manuals.

Total capital investment for Plant Type I equals 130% of battery-limit costs; for Plant Type II, 132% of battery-limit costs.

Capital cost data has been developed and is presented for the following four basic types of plants:

Plant Type IA - with waste heat boiler and bed coils and with cooling tower

Plant Type IB - with waste heat boiler and bed coils but no cooling tower

Plant Type IIA - no steam generation equipment but with cooling tower

Plant Type IIB - no steam generation equipment and no cooling tower

Fairly large quantities of cooling water are required for the FluoSolids pyrite roasting - contact acid manufacturing process. As shown in Figure III-6, cooling water is required for the heat exchanger which cools the water that is circulated through the multi-stage gas-scrubber-cooler in the gas cooling and cleaning section of the plant. Cooling water is also required for cooling both the 93% acid and the 98% acid in the acid-plant section of the plant. This cooling water may be provided by the use of

TABLE III-21

Battery Limit Costs and Total Capital Investment vs. Capa

(Millions of Dollars)

Capacity Factors (See Table 6)		Pyrite Plant				
		2		4		6
		1.0		0.897		0.833
TPD Capacity	TPY (98%) Acid	Bat. Lim. Cost	Tot. Cap. Invest.	Bat. Lim. Cost	Tot. Cap. Invest.	Bat. Lim. Cost
Plant Type IA { Steam, Cooling tower						
250	82500	3.16	4.14	3.52	4.60	3.80
500	165000	4.19	5.48	4.67	6.10	5.03
1000	330000	6.97	9.12	7.75	10.19	8.35
1500	495000	9.21	12.10	10.26	13.50	11.04
2500	825000	14.39	18.86	16.04	21.00	17.30
Plant Type IB { Steam, No cooling tower						
250	82500	3.11	4.07	3.47	4.54	3.74
500	165000	4.11	5.39	4.59	6.00	4.93
1000	330000	6.85	8.96	7.65	10.00	8.22
1500	495000	9.06	11.89	10.10	13.24	10.86
2500	825000	14.18	18.55	15.96	20.70	17.05
Plant Type IIA { Cooling tower No steam						
258	85000	2.87	3.82	3.20	4.27	3.44
517	170600	3.76	5.00	4.18	5.58	4.50
1033	340900	6.05	8.05	6.75	8.98	7.26
1550	511500	7.89	10.50	8.79	11.70	9.48
2583	852000	12.12	16.15	13.50	17.98	14.55
Plant Type IIB { No cooling tower No steam						
258	85000	2.76	3.67	3.07	4.08	3.30
517	170600	3.60	4.80	4.01	5.34	4.32
1033	340900	5.81	7.73	6.48	8.63	6.95
1550	511500	7.57	10.08	8.44	11.20	9.09
2583	852000	11.71	15.65	13.03	17.37	14.05

Plant Type	
I-A	Cooling tower and steam generation equipment.
I-B	Steam generation equipment but no tower.
II-A	Cooling tower, no steam generation equipment.
II-B	No cooling tower, no steam generation equipment.

A

TABLE III-21

apital Investment vs. Capacity and Feed Composition
(Millions of Dollars)

Pyrite Plant Feed Composition Numbers										
4		6		8		10		12		
0.897		0.833		0.783		0.673		0.530		
m.	Tot. Cap. Invest.	Bat. Lim. Cost	Tot. Cap. Invest.	Bat. Lim. Cost	Tot. Cap. Invest.	Bat. Lim. Cost	Tot. Cap. Invest.	Bat. Lim. Cost	Tot. Cap. Invest.
						Approx.		Order of Mag.	
	4.60	3.80	4.98	4.04	5.29	4.69	6.14	5.96	7.83
	6.10	5.03	6.59	5.35	7.00	6.21	8.15	7.91	10.31
	10.19	8.35	10.96	9.92	11.66	10.30	13.53	13.17	17.20
	13.50	11.04	14.54	11.78	15.42	13.67	17.95	17.40	22.80
	21.00	17.30	22.65	18.37	24.10	21.40	28.00	27.20	35.50
	4.54	3.74	4.88	4.06	5.20	4.61	6.05	5.80	7.60
	6.00	4.93	6.46	5.26	6.87	6.11	8.00	7.78	10.15
	10.00	8.22	10.76	8.75	11.46	10.16	13.31	12.95	16.91
	13.24	10.86	14.27	11.56	15.18	13.46	17.65	17.11	22.40
	20.70	17.05	22.25	14.21	23.70	21.00	27.55	26.80	35.00
	4.27	3.44	4.58	3.66	4.88	4.26	5.67	5.44	7.25
	5.58	4.50	6.00	4.78	6.38	5.56	7.51	7.10	9.45
	8.98	7.26	9.68	7.73	10.30	8.98	11.94	11.43	15.24
	11.70	9.48	12.61	10.10	13.45	11.70	15.60	14.88	19.80
	17.98	14.55	19.37	15.49	20.60	18.00	24.00	22.86	30.40
	4.08	3.30	4.39	3.52	4.68	4.09	5.44	5.22	6.93
	5.34	4.32	5.75	4.59	6.10	5.35	7.12	6.80	9.04
	8.63	6.95	9.25	7.42	9.87	8.60	11.45	10.98	14.60
	11.20	9.09	12.10	9.66	12.88	11.22	14.99	14.31	19.10
	17.37	14.05	18.73	14.95	19.90	17.35	23.12	22.10	29.40

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Plant Feed Composition

No.	% Pyrite	% Coal	% Gangue
2	90	5	5
4	80	7	13
6	85	10	5
8	70	10	20
10	70	15	15
12	65	23	12

B

an evaporative-type water-cooling tower such as is shown on the process flow diagram. Where a cooling tower has been included as part of the process equipment, this plant is referred to as Type A. Where there is no cooling tower and river water or some other water source is used to supply the necessary cooling water on a once-through basis, the plant is referred to as Type B.[1]

Battery-limit costs and total capital investment are presented in Table III-21 for the six different pyrite plant feed compositions for capacities of 250, 500, 1000, 1500 and 2500 tons per day of 98% product acid for Plant Type IA and IB and for capacities of 258, 517, 1033, 1550 and 2583 tons per day of 98% product acid for Plant Type IIA and IIB. An explanation of the difference in capacities for Plant Type I and Plant Type II is in order. The necessary process and equipment sizing information was developed for Plant Type I and capital costs determined for Plant Type I. The capital costs were then developed for Plant Type II from the same basic process and equipment sizing information, with appropriate changes in both sizing and costs as would be required for a plant with no steam generating equipment. However, these changes result in a slight difference in plant capacity, since it is estimated that only 90% recovery of sulfur can be achieved in Plant Type I while 93% recovery is realizable for Plant Type II. In all cases the annual acid production is based on 330 operating days per year or a 90.5% operating factor.

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[1] While a cooling tower would probably be required in a water-short area, such equipment should be used even where water is plentiful and inexpensive in order to minimize thermal pollution.

The total capital investment costs as shown in Table III-21 include the cost of land at $1000/acre for the plant proper, for offsite facilities, for storage of one month's supply of pyrite plant feed and 7 days' production of acid, and land for calcine disposal. The approximate land requirements for the various size plants are shown in Table III-22.

TABLE III-22

TOTAL LAND REQUIREMENTS
(acres)

	Plant Capacity (tons per day 98% acid)				
	250	500	1,000	1,500	2,500
Pyrite Storage (1 month's supply)	0.5	1.0	2.0	3.0	5.0
Battery Limit Plant (including acid storage)	1.0	1.5	2.0	3.0	5.0
Offsites	1.5	2.0	2.5	3.5	5.5
Sub Total	3.0	4.5	6.5	9.5	15.5
Calcine Disposal (for 10 years)[1]	15	30	60	90	150
Total Acres Required	18	35	66	100	165

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[1] If calcines were sold, acreage requirements would obviously be reduced - perhaps equivalent to the average needed for pyrite storage.

6. Operating Costs

Operating costs are generally considered in terms of direct operating costs and indirect operating costs, as is discussed below.

a. Direct Operating Costs

Items of direct operating costs would include: utilities such as power, fuel, water, chemicals, etc.; maintenance materials and supplies; and operating and maintenance labor. This study has been made on the basis that the most likely location of the plant would be in one or more of the following areas: Western Pennsylvania, Eastern Ohio, and Southern Illinois, and possibly in Kentucky, West Virginia, and the Chicago, Ill. - Gary, Indiana areas. In an effort to arrive at reasonably reliable utility and labor costs, we contacted such firms or organizations as chambers of commerce, industrial development commissions, public utilities, and agencies of the U.S. Department of Labor. Information was obtained for the following geographic areas or locations: Indiana County, Pennsylvania; Paducah, Kentucky; Cairo, Illinois; the greater St. Louis area; and the greater Chicago area. Based on information received from these sources in these areas, the following average unit costs were selected:

- Utilities

  Electrical Power -- 0.8 ¢ per Kilowatt-hour

  Fuel

  Natural Gas -- 40¢ per million Btu
  Bunker C Oil -- 40¢ per million Btu

  Water

  Cooling Water -- 5¢ per 1000 gallons
  Process Water -- 15¢ per 1000 gallons

- Labor (Operating and Maintenance)

  Average for all skills or trades -- $4.00 per man-hour

- Chemicals

  Lime (for acid neutralization)-- $18.00 per ton delivered

  Bentonite (for pelletizing of high grade Fe_2O_3 pellets)-- 1.5¢ per pound delivered

Cost of maintenance materials and supplies for contact acid plant section ranges from 40¢ per ton of 98% product acid for feed composition No. 2, to 72¢ per ton acid for feed composition No. 12 (for details, see Table III-27).

For FluoSolids pyrite-roasting and offsite facilities, 1.5% annually of total plant cost. The various direct operating requirements - water, labor, etc. - were determined as discussed below.

(1) Electrical Power --The power requirements for the four basic types of plants (IA, IB, IIA, and IIB) were determined on the basis of pyrite plant-feed composition No. 2 for all plant capacities from 250 to 2500 tons per day 98% product acid, as shown in Table III-23.

TABLE III-23

POWER REQUIREMENTS
(Pyrite Plant Feed Composition No. 2)
(For all Capacities from 250 to 2500 TPD Acid)

Plant Type	Power Required (kwh/ton acid)	Power Cost ($/ton acid)
IA (with waste heat boiler and cooling tower)	33.4	0.27
IB (with waste heat boiler but no cooling tower)	21.55	0.17
IIA (no steam generation equipment but with cooling tower)	115.3	0.92
IIB (no steam generation equipment and no cooling tower)	92.6	0.74

As the pyrite plant-feed grade decreases (less pyrite - more coal), the gas volumes increase in all sections of the plant, and the heat removal and therefore the boiler water and cooling water requirements in the roasting section of the plant increase at a rate equivalent to the process factors, as shown in Table III-17. Accordingly, the power costs for the other five grades of pyrite plant feed have been determined as shown in Table III-24.

TABLE III-24

POWER COST VERSUS PYRITE PLANT FEED CONSUMPTION

	Pyrite Plant Feed Composition Number					
	2	4	6	8	10	12
Process Factors (for roasting and acid manufacture)						
Plant Type IA and IB	1.0	1.115	1.20	1.28	1.48	1.88
Power Cost (Dollars/ Ton 98% Acid)						
Plant Type IA	0.27	0.30	0.32	0.34	0.40	0.50
Plant Type IB	0.17	0.19	0.21	0.22	0.26	0.33
Process Factors (for roasting and acid manufacture)						
Plant Type IIA and IIB	1.0	1.115	1.20	1.275	1.48	1.89
Power Cost (Dollars/ Ton 98% Acid)						
Plant Type IIA	0.92	1.03	1.11	1.17	1.37	1.74
Plant Type IIB	0.74	0.83	0.89	0.94	1.02	1.39

(2) Water -- Both process and cooling water requirements were determined for plant types IA, IB, IIA, and IIB and for all capacities from 250 to 2500 tons per day of 98% product acid based on pyrite plant feed composition No. 2, as shown in Table III-25.

TABLE III-25

WATER REQUIREMENTS FOR PYRITE FEED NO. 2 AND ALL CAPACITIES

Plant Type	Water Required (gal./ton acid)		Total Water Cost
	Process	Cooling	($/ton acid)
IA (Steam, tower)	283	1,036	0.09
IB (Steam, no tower)	143	16,390	0.84
IIA (Tower, no steam	193	1,021	0.08
IIB (No Tower, no steam)	27	27,450	1.38

As the pyrite plant feed grade decreases (less pyrite - more coal) the gas volumes per ton of product acid increase, and the heat generation and therefore the cooling requirements increase per ton of product acid; thus, water requirements increase with decreasing pyrite grade at a rate essentially equivalent to the process factors, as presented in Table III-17. Therefore, the water requirements and costs have been determined for the other five grades of pyrite feed as shown in Table III-26.

TABLE III-26

WATER COSTS VERSUS PYRITE PLANT FEED COMPOSITION

	Pyrite Plant Feed Composition Number					
	2	4	6	8	10	12
Process Factors for Plant Types IA and IB (for roasting and acid manufacture	1.0	1.115	1.20	1.28	1.48	1.88
Water Cost (Dollars/Ton 98% Acid)						
Plant Type IA	0.09	0.11	0.11	0.12	0.14	0.18
Plant Type IB	0.84	0.93	1.01	1.08	1.25	1.58
Process Factors for Plant Types IIA and IIB (for roasting and acid manufacture)	1.0	1.115	1.20	1.275	1.48	1.89
Water Cost (Dollars/Ton 98% Acid)						
Plant Type IIA	0.08	0.08	0.09	0.11	0.12	0.15
Plant Type IIB	1.38	1.53	1.65	1.75	2.03	2.61

(3) Lime -- Lime is required for neutralization of weak, contaminated acid from the roaster gas cooling and cleaning equipment and for neutralizing soluble sulfates in the calcines. The lime requirements were determined on the basis of 90% available CaO in the lime and with 25% excess lime being added to the waste acid streams to insure proper neutralization. On this basis the lime required for Plant Types IA and IB is 57.5 pounds of lime per ton of 98% product acid and for Plant Types IIA and IIB is 7.2 pounds lime per ton of 98% product acid. The great difference in the lime requirements is due to the fact that only a small portion of the weak acid can be returned to

the roaster in Plant Type I, whereas the bulk of the weak acid can be returned to the roaster in Plant Type II. At a delivered cost of $18/ton of lime, the costs are $0.52 and $0.07/ton of 98% product acid for Plant Type I and Plant Type II respectively.

(4) Maintenance Materials and Supplies -- The cost of maintenance materials and supplies for the contact acid plant section of the plant for the highest grade pyrite (plant feed No. 2) is about 40¢ per ton of 98% product acid. As the pyrite plant-feed grade decreases (less pyrite, more coal), the gas volume per unit of SO_2 or H_2SO_4 increases. This requires a larger plant - i.e., larger SO_2 blower, larger convertor requiring more vanadium pentoxide catalyst, larger heat exchangers, etc. For this reason the maintenance cost for materials and supplies for the contact acid plant will increase, and these were determined on the basis of the process factors presented in Table III-17 with the resultant costs as shown below in Table III-27.

TABLE III-27

MAINTENANCE MATERIALS AND SUPPLIES FOR CONTACT ACID PLANT SECTION

(dollars/ton 98% product acid)

	Pyrite Plant Feed Composition Number					
	2	4	6	8	10	12
Process Factors (for contact acid plant)	1.0	1.12	1.19	1.26	1.44	1.80
Maintenance Materials and Supplies (Dollars/Ton 98% acid)	0.40	0.45	0.48	0.50	0.58	0.72

The cost of maintenance materials and supplies for the balance of the plant, FluoSolids pyrite roasting and offsite facilities, were based on 1.5% annually of the total plant cost on the basis of a 90.5% operating factor or 330 days/year.

On the basis discussed above, the total cost for maintenance materials and supplies are as presented in Table III-28.

(5) Labor -- Both operating labor and maintenance labor will depend upon the basic type of plant and upon the number of lines or trains of FluoSolids pyrite roasters and of contact acid plant trains or lines. Plant Type I, with steam generating bed coils in the reactor and a waste-heat boiler, can be expected to require somewhat more operating labor and definitely more maintenance labor than would be needed for Plant Type II, which has no steam generating equipment.

As the grade of pyrite plant-feed decreases (less pyrite, more coal) the number of lines of roasters and of lines of acid plants will increase. The number of lines of equipment has been determined as per Table III-29 on the basis of the capacity factors as presented in Table III-17.

Using the number of lines of equipment required for the different grades of pyrite plant feed and for the different acid production capacities, determination of operating labor and of maintenance labor requirements were estimated as is illustrated in Table III-30 for pyrite plant feed composition No. 2.

TABLE III-28

Cost of Maintenance Materials and Supplies vs. Plant Capacity and Pyrite Plant Feed Composition
(Dollars per Ton of 98% Acid Product)

Plant Type		Pyrite Plant Feed Composition Number											
		2		4		6		8		10		12	
Plant Capacity (98%) Product Acid TPD	TPY	IA	IB	IA	IB	IA	IB	IA	IB	IA	IB	IA	IB
250	82,500	0.74	0.73	0.82	0.82	0.88	0.88	0.93	0.92	1.08	1.07	1.35	1.34
500	165,000	0.62	0.62	0.70	0.70	0.75	0.75	0.79	0.78	0.91	0.91	1.14	1.14
1,000	330,000	0.60	0.60	0.67	0.67	0.72	0.72	0.76	0.76	0.88	0.88	1.10	1.10
1,500	495,000	0.59	0.59	0.66	0.66	0.71	0.71	0.74	0.74	0.86	0.86	1.08	1.07
2,500	825,000	0.58	0.58	0.65	0.65	0.70	0.69	0.73	0.73	0.85	0.85	1.06	1.06

Plant Type													
Plant Capacity (98%) Product Acid TPD	TPY	IIA	IIB	IIA	IIB	IIA	IIB	IIA	IIB	IIA	IIB	IIA	IIB
258	85,000	0.74	0.73	0.83	0.82	0.89	0.88	0.93	0.92	1.08	1.07	1.36	1.34
517	170,600	0.62	0.62	0.70	0.69	0.75	0.74	0.78	0.78	0.91	0.90	1.14	1.13
1,033	340,900	0.57	0.56	0.64	0.63	0.68	0.68	0.72	0.71	0.83	0.82	1.04	1.03
1,550	511,500	0.54	0.53	0.60	0.60	0.64	0.64	0.68	0.67	0.78	0.78	0.98	0.97
2,583	852,000	0.53	0.52	0.59	0.59	0.63	0.63	0.66	0.66	0.77	0.76	0.96	0.95

Plant Type	
I-A	Cooling tower and steam generation equipment.
I-B	Steam generation equipment but no tower.
II-A	Cooling tower, no steam generation equipment.
II-B	No cooling tower, no steam generation equipment.

	Plant Feed Composition		
No.	% Pyrite	% Coal	% Gangue
2	90	5	5
4	80	7	13
6	85	10	5
8	70	10	20
10	70	15	15
12	65	23	12

TABLE III-29

Number of Roaster Lines and Contact Acid Lines
vs.
Plant Capacity and Pyrite Plant Feed Composition

		Pyrite Plant Feed Composition Numbers											
		2		4		6		8		10		12	
FluoSolids Pyrite Roasting													
Capacity Factors		1.0		0.9		0.827		0.7725		0.654		0.505	
Approx. Maximum Capacity/Line - TPD Acid		500		450		413		387		327		253	
Number of Lines Required										Approx.		Order of Mag.	
Plant Type I TPD Capacity	Plant Type II TPD (98%) Acid	Theoret.	Actual	Theoret.	Actual	Theoret.	Actual	Theoret.	Actual	Theoret.	Actual	Theoret.	Actual
250	258	1	1	1	1	1	1	1	1	1	1	1	1
500	517	1	1	1.11	1	1.21	1	1.3	1	1.53	2	1.98	2
1,000	1,033	2	2	2.22	2	2.42	2	2.6	3	3.06	3	3.96	4
1,500	1,550	3	3	3.33	3	3.63	4	3.9	4	4.59	5	5.94	6
2,500	2,583	5	5	5.55	6	6.05	6	6.5	7	7.65	8	9.90	10
Contact Acid Plant													
Capacity Factors		1.0		0.893		0.84		0.795		0.695		0.555	
Approx. Maximum Capacity/Line - TPD Acid		1500		1340		1260		1190		1040		833	
Number of Lines Required										Approx.		Order of Mag.	
Plant Type I TPD	Plant Type II TPD (98%) Acid	Theoret.	Actual	Theoret.	Actual	Theoret.	Actual	Theoret.	Actual	Theoret.	Actual	Theoret.	Actual
250	258	1	1	1	1	1	1	1	1	1	1	1	1
500	517	1	1	1	1	1	1	1	1	1	1	1	1
1,000	1,033	1	1	1	1	1	1	1	1	1	1	1.2	1
1,500	1,550	1	1	1.12	1	1.19	1	1.26	1	1.44	1	1.8	2
2,500	2,583	2	2	2	2	2	2	2.1	2	2.4	2	3.0	3

No.	Plant Feed Composition % Pyrite	% Coal	% Gangue
2	90	5	5
4	80	7	13
6	85	10	5
8	70	10	20
10	70	15	15
12	65	23	12

Plant Type	
I-A	Cooling tower and steam generation equipment.
I-B	Steam generation equipment but no tower.
II-A	Cooling tower, no steam generation equipment.
II-B	No cooling tower, no steam generation equipment.

TABLE III-30

Operating Labor and Maintenance Labor Requirements For Pyrite Plant Feed Composition Number 2

	Plant Type IA and IB					Plant Type IIA and IIB				
Plant Capacity - TPD (98%) Product Acid	250	500	1000	1500	2500	258	517	1033	1550	2583
Number of Lines Required										
FluoSolids Pyrite Roasting	1	1	2	3	5	1	1	2	3	5
Contact Acid Plant	1	1	1	1	2	1	1	1	1	2
Operating Labor (Mandays/24 hour day)										
FluoSolids Pyrite Roasting	10	10	13	16	25	7	7	10	13	20
Contact Acid Plant	7	7	7	7	12	7	7	7	7	12
Offsite Facilities	10	10	10	10	15	8	8	8	8	11
Shift Foremen (Total Plant)	3	3	3	3	3	3	3	3	3	3
Total Operating	30	30	33	36	55	25	25	28	31	46
Maintenance Labor (Mandays/24 hour day)										
FluoSolids Pyrite Roasting	4	4	5	7	9	3	3	4	6	8
Contact Acid Plant	4	4	5	6	10	4	4	5	6	10
Offsite Facilities	4	4	4	4	6	3	3	3	3	5
Supervisor (Total Plant)	1	1	1	1	1	1	1	1	1	1
Total Maintenance	13	13	15	18	26	11	11	13	16	24
Total Direct Operating and Maintenance Labor (Mandays per 24 hour day)	43	43	48	54	81	36	36	41	47	70

Plant Type

I-A Cooling tower and steam generation equipment.

I-B Steam generation equipment but no tower.

II-A Cooling tower, no steam generation equipment.

II-B No cooling tower, no steam generation equipment.

	Plant Feed Composition		
No.	% Pyrite	% Coal	% Gangue
2	90	5	5
4	80	7	13
6	85	10	5
8	70	10	20
10	70	15	15
12	65	23	12

Using this same general staffing arrangement, i.e., labor requirement as a function of the number of lines of FluoSolids pyrite roasters and lines of contact acid plants, labor requirements for all six grades of pyrite plant feed were determined for capacities from 250 to 2500 tons per day of 98% product acid. The direct operating labor costs and the direct maintenance labor costs were determined based on an average hourly wage of $4.00/man hour. These costs are shown in the following Table III-31, expressed in terms of dollars per ton of 98% product acid.

All the direct operating costs including power, water, lime, maintenance materials and supplies, and operating and maintenance labor are summarized in Table III-32.

In any process industry project there are certain indirect costs, which include such items as labor overhead, taxes and insurance, interest on working capital, and depreciation of the plant,as are discussed below.

b. Indirect Operating Costs

Operation of a process facility as is being considered here requires a certain amount of labor over and above that required for the direct operation and maintenance of the facility. Such labor would include administrative, managerial, sales, and service labor -- commonly referred to as labor overhead. Specifically, this would include the items listed below:

(1) Plant Administrator or Manager;

(2) Operations Director;

(3) Office Services, including office manager, clerk, accountant or bookkeeper, secretary and typist, janitor, etc;

(4) Maintenance Services, including shop foreman, shop machine operators, truck driver, etc.;

(5) General Services, including plant and/or lab chemist, plant guards and/or watchmen, and stock or warehouse clerk;

(6) Sales expenses;

(7) Office supplies, telephone, telegraph, travel, etc.; and

(8) Miscellaneous labor overhead not included above.

Labor overhead is generally best expressed for this type of process facility in relation to the direct operating labor requirements and has been included, at 100% of direct operating labor, in the indirect operating cost.

Taxes and insurance are included as part of the indirect operating costs at 2% of the total capital investment. A certain amount of working capital must be maintained for day-to-day operation of the plant, and the interest on this working capital is an indirect operating cost. Based on a working capital of 5% of total capital investment at 6% interest, this interest on working capital amounts to 0.3% annually.

Plant depreciation has been taken over a 10-year period on the basis of 100% equity (no borrowed capital) and on this basis is included in the indirect operating cost at 10% of the total capital investment. In summation, the total indirect operating costs have been determined as shown in Table III-33.

TABLE III-31

Direct Operating and Maintenance Labor Cost vs. Pyrite Plant Feed Composition and Plant Capacity

(Dollars Per Ton of 98% Product Acid)

		Pyrite Plant Feed Composition Number											
		2		4		6		8		10		12	
Plant Type ⟶		I	II	I	II	I	II	I	II	I	II	I	II
OPERATING LABOR													
Plant Capacity - TPD (98%) Acid													
Plant Type I	Plant Type II												
250	258	4.24	3.44	4.24	3.44	4.24	3.44	4.24	3.44	4.24	3.44	4.24	3.44
500	517	2.12	1.71	2.12	1.71	2.12	1.71	2.12	1.71	2.34	1.92	2.34	1.92
1000	1033	1.17	0.96	1.17	0.96	1.17	0.96	1.31	1.06	1.31	1.10	1.45	1.27
1500	1550	0.85	0.71	0.85	0.71	0.94	0.82	0.94	0.82	1.04	0.89	1.44	1.21
2500	2583	0.78	0.63	0.88	0.73	0.88	0.73	0.98	0.81	1.08	0.88	1.45	1.20
MAINTENANCE LABOR													
Plant Capacity - TPD (98%) Acid													
Plant Type I	Plant Type II												
250	258	1.84	1.51	1.84	1.51	1.84	1.51	1.84	1.51	1.84	1.51	1.84	1.51
500	517	0.92	0.75	0.92	0.75	0.92	0.75	0.92	0.75	1.06	0.89	1.06	0.89
1000	1033	0.53	0.45	0.53	0.45	0.53	0.45	0.60	0.55	0.60	0.51	0.67	0.58
1500	1550	0.43	0.37	0.43	0.37	0.47	0.41	0.47	0.41	0.52	0.48	0.71	0.64
2500	2583	0.37	0.33	0.41	0.38	0.41	0.38	0.45	0.43	0.50	0.47	0.68	0.63
TOTAL DIRECT OPERATING AND MAINTENANCE LABOR													
Plant Capacity - TPD (98%) Acid													
Plant Type I	Plant Type II												
250	258	6.08	4.95	6.08	4.95	6.08	4.95	6.08	4.95	6.08	4.95	6.08	4.95
500	517	3.04	2.46	3.04	2.46	3.04	2.46	3.04	2.46	3.40	2.81	3.40	2.81
1000	1033	1.70	1.41	1.70	1.41	1.70	1.41	1.91	1.61	1.91	1.61	2.12	1.85
1500	1550	1.28	1.08	1.28	1.08	1.41	1.23	1.41	1.23	1.56	1.37	2.15	1.85
2500	2583	1.15	0.96	1.29	1.11	1.29	1.11	1.43	1.24	1.58	1.35	2.13	1.83

Plant Type	
I-A	Cooling tower and steam generation equipment.
I-B	Steam Generation equipment but no tower.
II-A	Cooling tower, no steam generation equipment.
II-B	No cooling tower, no steam generation equipment.

	Plant Feed Composition		
No.	% Pyrite	% Coal	% Gangue
2	90	5	5
4	80	7	13
6	85	10	5
8	70	10	20
10	70	15	15
12	65	23	12

TABLE III-32

Total Direct Operating Costs (Dollars Per Ton 98% Acid)
(Power, Water, Lime, Maintenance Materials & Supplies, Direct Operating and Maintenance Labor)

Plant Capacity - TPD (98%) Product Acid		Pyrite Plant Feed Composition Number											
		2		4		6		8		10		12	
Plant Type →		IA	IIA	IA	IIA	IA	IIA	IA	IIA	IA	IIA	IA	IIA
Plant Type I	Plant Type II									Approx.		Order of Mag.	
250	258	7.70	6.76	7.83	6.96	7.91	7.10	7.99	7.23	8.22	7.59	8.63	8.27
500	517	4.54	4.15	4.67	4.34	4.74	4.48	4.81	4.59	5.25	5.28	5.74	5.91
1000	1033	3.18	3.05	3.30	3.23	3.37	3.36	3.65	3.68	3.85	4.00	4.42	4.85
1500	1550	2.75	2.69	2.87	2.86	3.07	3.14	3.13	3.26	3.48	3.71	4.43	4.79
2500	2583	2.61	2.56	2.87	2.88	2.94	3.01	3.14	3.25	3.49	3.68	4.39	4.75
Plant Type →		IB	IIB	IB	IIB	IB	IIB	IB	IIB	IB	IIB	IB	IIB
Plant Capacity - TPD (98%) Product Acid													
Plant Type I	Plant Type II									Approx.		Order of Mag.	
250	258	8.34	7.87	8.54	8.20	8.70	8.44	8.82	8.63	9.18	9.22	9.85	10.36
500	517	5.19	5.27	5.38	5.58	5.53	5.81	5.64	6.00	6.34	6.91	6.97	8.01
1000	1033	3.83	4.16	4.01	4.47	4.16	4.70	4.49	5.08	4.82	5.63	5.65	6.95
1500	1550	3.40	3.80	3.58	4.11	3.86	4.48	3.97	4.66	4.45	5.35	5.65	6.89
2500	2583	3.26	3.67	3.58	4.13	3.72	4.35	3.98	4.66	4.46	5.31	5.62	6.85

Plant Type	
I-A	Cooling tower and steam generation equipment.
I-B	Steam generation equipment but no tower.
II-A	Cooling tower, no steam generation equipment.
II-B	No cooling tower, no steam generation equipment.

Plant Feed Composition

No.	% Pyrite	% Coal	% Gangue
2	90	5	5
4	80	7	13
6	85	10	5
8	70	10	20
10	70	15	15
12	65	23	12

TABLE III-33

BASIS OF INDIRECT OPERATING COSTS

Labor Overhead	100% of direct operating labor
Other Indirect Operating Costs	% of Total Capital Investment
Taxes and Insurance	2.0
Interest on Working Capital (5% of total capital investment @ 6% interest)	0.3
Plant Depreciation (10 years 100% equity)	10.0
Total	12.3

Indirect operating costs based on the values shown in Table III-33 are presented in Table III-34.

c. Total Operating Costs

The direct operating costs plus the indirect operating cost add up to the total cost of processing the pyrite to produce sulfuric acid. These "Total Processing Costs" are summarized in Table III-35 for the four different types of plants (IA, IIA, IB, and IIB), for the six different grades of pyrite plant feeds, and for plant capacities from 250 to 2500 tons per day of 98% product acid. These processing costs start with pyrite plant feed in a storage pile at the plant site and end with product acid in storage tanks at the plant

TABLE III-34

Total Indirect Operating Costs vs. Pyrite Plant Feed Composition and Plant Capacity
(Dollars Per Ton 98% Product Acid)

		Pyrite Plant Feed Composition Number											
		2		4		6		8		10		12	
Plant Type →		IA	IIA	IA	IIA	IA	IIA	IA	IIA	IA	IIA	IA	IIA
Plant Capacity - TPD (98%) Acid										Approx.		Order of Mag	
Plant Type I	Plant Type II												
250	258	10.41	8.87	11.09	9.61	11.68	10.07	12.12	10.50	13.39	11.64	15.89	13.94
500	517	6.20	5.32	6.67	5.74	7.02	6.04	7.34	6.31	8.41	7.34	10.00	8.74
1000	1033	4.57	3.87	4.97	4.20	5.26	4.46	5.66	4.78	6.37	5.41	7.87	6.77
1500	1550	3.85	3.23	4.20	3.52	4.56	3.86	4.77	4.06	5.49	4.64	7.10	5.97
2500	2583	3.59	2.95	4.01	3.32	4.26	3.52	4.58	3.78	5.25	4.34	6.75	5.57
Plant Type →		IB	IIB	IB	IIB	IB	IIB	IB	IIB	IB	IIB	IB	IIB
Plant Capacity - TPD (98%) Acid										Approx.		Order of Mag	
Plant Type I	Plant Type II												
250	258	10.30	8.75	11.00	9.34	11.51	9.79	11.99	10.21	13.24	11.30	15.55	13.44
500	517	6.14	5.17	6.59	5.56	6.94	5.86	7.24	6.11	8.30	7.05	9.89	8.44
1000	1033	4.51	3.75	4.90	4.08	5.18	4.30	5.58	4.62	6.28	5.23	7.77	6.54
1500	1550	3.80	3.13	4.14	3.40	4.48	3.73	4.71	3.92	5.42	4.49	7.00	5.81
2500	2583	3.54	2.89	3.96	3.23	4.20	3.43	4.51	3.68	5.18	4.21	6.67	5.43

Plant Type	
I-A	Cooling tower and steam generation equipment.
I-B	Steam generation equipment but no tower.
II-A	Cooling tower, no steam generation equipment.
II-B	No cooling tower, no steam generation equipment.

	Plant Feed Composition		
No.	% Pyrite	% Coal	% Gangue
2	90	5	5
4	80	7	13
6	85	10	5
8	70	10	20
10	70	15	15
12	65	23	12

TABLE III-35

Total Processing Costs (Direct & Indirect Costs) (Dollars Per Ton of 98% Product Acid)
vs.
Pyrite Plant Feed Composition and Plant Capacity

		Pyrite Plant Feed Composition Number											
		2		4		6		8		10		12	
%Pyrite		90		80		85		70		70		65	
%Coal		5		7		10		10		15		23	
%Inerts		5		13		5		20		15		12	
S/C Ratio		13.8		8.7		6.5		5.36		3.58		2.2	
S/H_2 Ratio		182		116		86		71		47.5		29	
Plant Type →		IA	IIA	IA	IIA	IA	IIA	IA	IIA	IA	IIA	IA	IIA
Plant Capacity - TPD (98%) Acid										Approx.		Order of Mag.	
Plant Type I	Plant Type II												
250	258	18.11	15.63	18.92	16.57	19.59	17.17	20.11	17.73	21.61	19.23	24.53	22.21
500	517	10.74	9.47	11.34	10.08	11.76	10.52	12.15	10.90	13.66	12.62	15.74	14.65
1000	1033	7.75	6.92	8.27	7.43	8.63	7.82	9.31	8.46	10.22	9.41	12.29	11.62
1500	1550	6.60	5.92	7.07	6.38	7.63	7.00	7.90	7.32	8.97	8.35	11.53	10.76
2500	2583	6.20	5.51	6.88	6.20	7.20	6.53	7.72	7.03	8.74	8.02	11.14	10.32
Plant Type →		IB	IIB	IB	IIB	IB	IIB	IB	IIB	IB	IIB	IB	IIB
Plant Capacity - TPD (98%) Acid										Approx.		Order of Mag.	
Plant Type I	Plant Type II												
250	258	18.64	16.62	19.54	17.54	20.21	18.23	20.81	18.84	22.42	20.52	25.40	23.80
500	517	11.33	10.44	11.97	11.14	12.47	11.67	12.88	12.11	14.64	13.96	16.86	16.45
1000	1033	8.34	7.91	8.91	8.55	9.34	9.00	10.07	9.70	11.10	10.86	13.42	13.49
1500	1550	7.20	6.93	7.72	7.51	8.34	8.21	8.68	8.58	9.87	9.84	12.65	12.70
2500	2583	6.80	6.56	7.54	7.36	7.92	7.78	8.49	8.34	9.64	9.52	12.29	12.28

Plant Type		
	I-A	Cooling tower and steam generation equipment.
	I-B	Steam generation equipment but no tower.
	II-A	Cooling tower, no steam generation equipment.
	II-B	No cooling tower, no steam generation equipment.

site. The cost of disposing of the calcines and neutralization and disposal of weak waste acid is included in these processing costs. However, the following specific cost items are not included in these processing costs:

(1) Cost of producing or purchasing pyrite plant feed;

(2) Cost of moving (loading, shipping, unloading) the pyrite from the point of production of the pyrite to the storage pile at the pyrite roasting - acid plant site;

(3) Cost of moving (pumping, loading, shipping, unloading) the product acid from the storage tanks at the plant site to the point of acid consumption;

(4) Any by-product credits such as

- Credit for low-pressure turbine exhaust steam, or
- Credit for calcines either in the form as produced or after possible conversion to high grade Fe_2O_3 pellets; and

(5) Indirect credits such as

- Increased value of beneficiated coal from which pyrite is derived that might be assigned to either the coal producer or the coal consumer, including the meeting of air pollution codes or specifications.
- Benefits that might be derived by virtue of decreased amounts of plant refuse of lower sulfur content at the coal beneficiation or coal-cleaning plant.

C. CALCINE UTILIZATION

In the roasting of the pyrite plant-feed, the pyrite, FeS_2, is oxidized to form SO_2 and Fe_2O_3. The gangue or inerts in the pyrite plant feed goes through the roasting operation unaltered, except for removal of any bound or hydrate moisture that may be eliminated at the roasting temperature and remains with the Fe_2O_3. The ash in the coal portion of the pyrite plant feed will also stay with the Fe_2O_3 in the calcines. The amount and approximate composition of the calcines from the various grades of pyrite plant feed have been presented in Table III-15.

The calcines from the roasting plant may be considered as a by-product credit to the operation if the calcines can be sold to the steel industry or others for their contained iron values. The trend in pig iron production seems to be for increased amounts of prepared burdens for the blast furnace. This has in some cases resulted in a deficiency of iron-containing fines at the steel mills to meet the need for fines in their sintering plants, leading to a possible market for the pyrite calcines.

The amount and approximate composition of pyrite calcines resulting from roasting are as shown in Table III-36. Just how acceptable the pyrite calcines will be to the steel industry or other possible users will depend not only upon the calcines' iron content but also on the amount of impurities that may be present in them and on their size analyses.

With regard to iron content, the steel industry in general is prone to accept material only if it contains at least 60% Fe. As shown in Table III-36,

TABLE III-36

Amount and Approximate Analyses of Calcines

		Pyrite Plant Feed Composition Number											
		2		4		6		8		10		12	
Pyrite Feed Composition (Weight % Dry)													
Pyrite		90		80		85		70		70		65	
Coal		5		7		10		10		15		23	
Inerts		5		13		5		20		15		12	
Total		100		100		100		100		100		100	
Plant Type		I	II	I	II	I	II	I	II	I	II	I	II
Pounds Pyrite Feed/Ton (98%) Acid		1470	1425	1660	1605	1550	1500	1890	1830	1880	1820	2000	1935
Pounds Calcines/Ton (98%) Acid		960	930	1110	1070	970	940	1275	1235	1180	1140	1150	1110
Pounds Iron/Ton (98%) Acid		615	595	615	595	615	595	615	595	614	593	613	592
Annual Calcine Production Short Tons/Year (330 days/year)													
Plant Capacity - TPD 98% Acid													
Plant Type I	Plant Type II												
250	258	39,500		45,750		40,000		52,500		48,750		47,500	
500	517	79,000		91,500		80,000		105,000		97,500		95,000	
1000	1033	158,000		183,000		160,000		210,000		195,000		190,000	
1500	1550	237,000		274,500		240,000		315,000		292,500		285,000	
2500	2583	395,000		457,500		400,000		525,000		487,500		475,000	
Approximate Calcine Composition (Weight %)													
Fe		64.3		55.8		63.4		48.2		52.0		53.2	
Fe_2O_3		92		79.7		90.5		68.9		74		76	
Inerts (Gangue & Coal Ash)		8		20.3		9.5		31.1		26		24	
Total S - approx.		± 1.8	± 1.5	± 1.6	± 1.3	± 1.8	± 1.5	± 1.4	± 1.1	± 1.5	± 1.2	± 1.5	± 1.2

Plant Type I - Steam generation equipment

Plant Type II - No steam generation equipment the calcines occurring from feed compositions 2-12 vary in iron content from 48.2% (No. 8) to 64.3% (No. 2). Feed composition No. 6, selected for use in estimating the economics of acid manufacture in an integrated fertilizer operation (Chapter V) has an iron content of 63.4%.

The calcine composition will naturally depend upon what happens to the pyrite impurities in the roasting operation. The amount of information on the kind and amount of impurities that may be expected in coal-derived pyrite seems very limited. Possible impurities that must be taken into account if the calcines are to be considered as a source of iron for the steel industry would include: silicon, aluminum, calcium, magnesium, and titanium oxides; phosphorus, sulfur, and arsenic; sodium, potassium, vanadium, chromium, nickel, copper, zinc, and lead. Most of these impurities would be associated with the gangue portion of the pyrite feed and with the ash portion of the coal. However, some of the metals such as copper, lead, zinc, arsenic, and nickel may occur with the pyrite, FeS_2. Most of the sources that were investigated were of the opinion that the arsenic content of pyrite from coal would be quite low. Also, some of the arsenic would be eliminated in roasting, except for cases where the pyrite feed contains appreciable free calcium and magnesium oxides. In these cases the arsenic usually reports to the calcines as calcium and magnesium arsenates. The sulfur that is present in the calcines is in the form of sulfate sulfur and residual or unreacted sulfide sulfur. An appreciable amount of the sulfide sulfur, and also of the sulfate present as such metal sulfates as iron, aluminum, copper, zinc, and nickel, would be eliminated in the sintering operation.

The size analyses of the calcines will be a function of the size analyses of the pyrite plant feed and a function of the amount of decrepitation or breakdown of the pyrite during roasting. It is to be anticipated that the pyrite plant-feed would have a maximum size such that it would all pass through a 1/4-inch screen. A minimum size such that all the material would pass a 28-mesh screen might be expected. The size analyses will depend upon the specific processing steps that are used in recovering the pyritic material from the coal-preparation-plant refuse. The amount of decrepitation during roasting will vary from one pyrite to another and also will depend upon the type of pyrite roaster and the roasting conditions. Because so little pyrite derived from coal is now being roasted for acid production, there appears to be very little or no information about decrepitation during roasting. The information that has been obtained concerning decrepitation was from small-scale laboratory FluoSolids roasting tests on two samples of pyrite (coal brass). One sample was a domestic sample from a midwestern utility company and the second sample was from Brazil. The chemical analyses and size analyses of the pyrite (coal brass) feed and calcines are shown following in Table III-37. As is shown, sample No. 1 decrepitated about 1 mesh during roasting. For sample No. 2 decrepitation amounted to 1 to 2 meshes. It is not known if the amount of decrepitation that took place with these two particular samples is typical of all coal brasses.

TABLE III-37

ANALYSES OF COAL BRASS SAMPLES

	Pyrite (Coal Brass)			
	Feed		Calcines	
Chemical Analyses (Wt.%)	No. 1	No. 2	No. 1	No. 2
Sulfur	44.3	42.9	1.0	1.3
Iron	40.2	40.6	56.8	67.0
Carbon	4.8	6.6	0.05	0.11
Acid Insol.	6.5	3.4	-	-

Size Analyses (Tyler Mesh)	Sample No. 1 Feed (cumulative %)	Sample No. 1 Calcines (cumulative %)	Sample No. 2 Feed (cumulative %)	Sample No. 2 Calcines (cumulative %)
10	0.1	0.1	-	-
14	3.7	2.9	-	-
20	13.2	10.5	0.1	-
28	30.7	24.3	17.9	10.2
35	45.6	36.2	40.4	23.7
48	61.0	48.3	60.5	39.9
65	75.2	59.7	74.3	54.7
100	90.4	71.8	84.1	71.4
150	97.8	74.6	90.5	73.2
200	99.4	85.0	94.5	78.2

NOTE: Sample No. 1 from Midwestern Utility Company
Sample No. 2 from Brazil

As is shown in Table III-36, the amount and composition of the calcines vary and are a function of the pyrite/inerts ratio in the pyrite plant feed. However, in that the sulfur is derived predominately from the pyrite, the amount of iron or iron oxide (Fe_2O_3) produced per unit of H_2SO_4 is essentially constant for all six grades of pyrite feed. As is shown in Table III-36, 615 pounds iron is produced per ton of 98% product acid for Plant Type I, and 595 pounds iron for Plant Type II. Based on about 95% recovery of iron values in the calcines in a form suitable for shipping to the steel industry, there would be available for possible credit to the operation 585 and 565 pounds iron, as Fe_2O_3, for Plant Type I and II respectively.

The iron ore and steel industries deal in terms of long tons (2240 pounds) and in terms of units of iron in the marketing of iron ores. A unit of iron is 22.4 pounds of iron. In the terms of iron units there would be 26.1 units of iron in the calcines/ton of 98% product acid for Plant Type I and 25.2 iron units/ton 98% product acid for Plant Type II. Assigning various values for the iron, the possible calcine credit would be as shown in Table III-38. These figures exclude any shipping charges for moving the calcines from the plant site to the steel mill.

Another approach to calcine utilization could be to further process the calcines to eliminate most of the inerts (gangue and coal ash) and thereby produce a higher grade material of lower impurities content. This is being done in Italy by the Montecatini - Dorr-Oliver process. In this process the hot calcines from the pyrite-roasting reactor are fed directly to a second

TABLE III-38

POSSIBLE CALCINE VALUES OR CREDITS

		Plant Type I	Plant Type II
Units of Iron in Calcines per Ton of (98%) Product Acid		26.1	25.2
Value of Calcines - (Dollars/Ton Acid)			
at 2 cents per iron unit		0.52	0.50
at 4 cents per iron unit		1.04	1.00
at 6 cents per iron unit	current probable price level	1.57	1.51
at 8 cents per iron unit		2.09	2.02
at 10 cents per iron unit		2.61	2.52
at 12 cents per iron unit		3.13	3.02

reactor in which they are reduced from the hematite to the magnetic state. The reducing atmosphere may be supplied by partial combustion of bunker C oil injected directly into the fluidized bed.

The hot, reduced calcines are fed into a third fluid bed, in which they are fluidized by low-pressure steam and cooled by water sprayed on the bed. The cooled calcines are discharged to the magnetic concentration section. A schematic flowsheet illustrating this process is shown in Figure III-7.

Cooled calcines recovered from the FluoSolids reduction are ground to the point of iron liberation and are concentrated on standard wet and dry magnetic separators. Pelletization may be performed on the magnetic concentrates in any one of a number of pelletizing grates now on the market. The final product is a high-grade Fe_2O_3 pellet about 1/4 to 3/8" diameter and of 60 to 65% iron content.

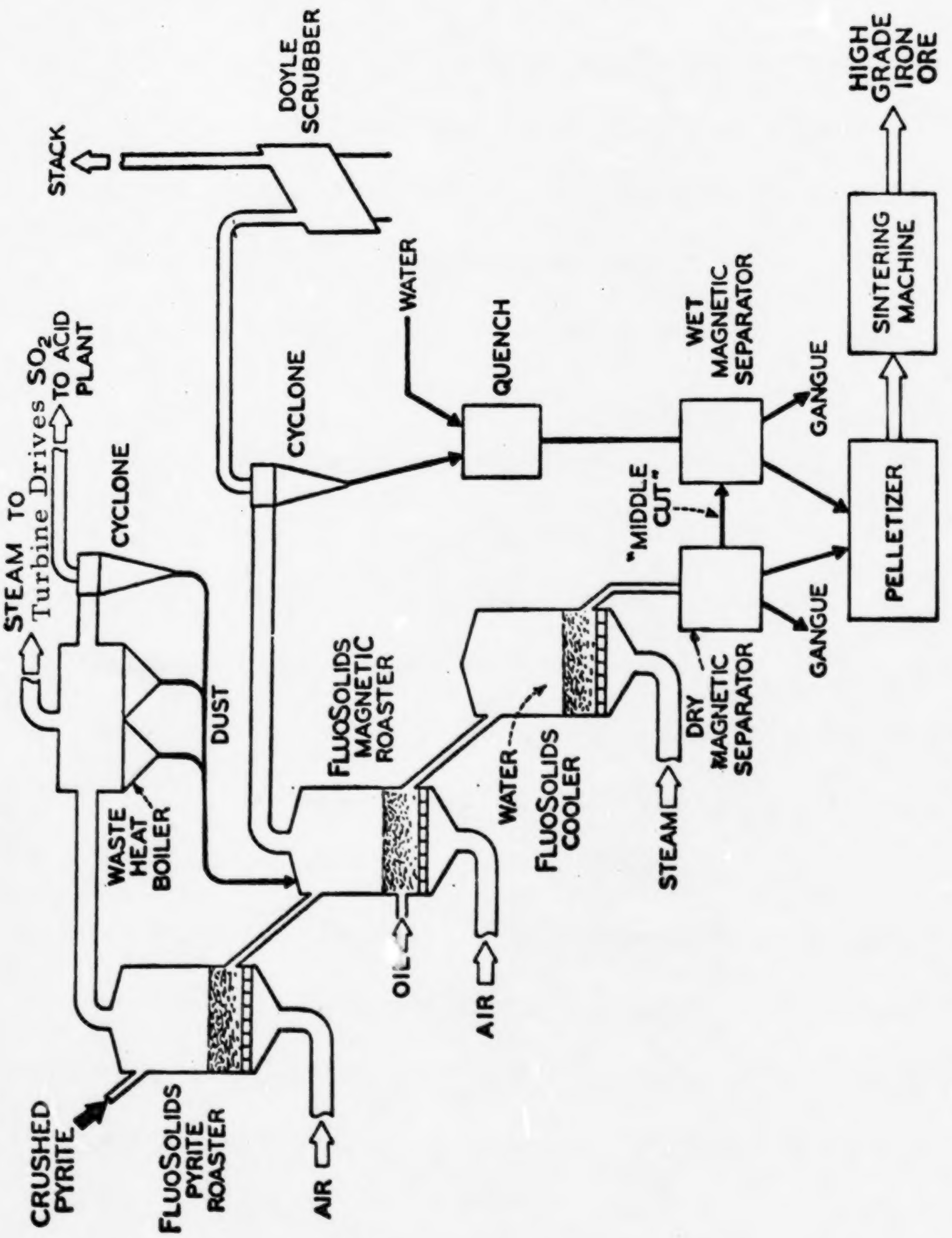

FIGURE III-7 FLUID-BED PROCESS FOR REDUCING PYRITE TO IRON
(Montecatini S.G., Follonica, Italy)

The cost of processing the calcines from the pyrite roaster using this process is presented in Table III-39. The determination of direct operating costs were made using the same unit costs for utilities, labor, etc., as were used for the pyrite roasting-contact acid plant. Also the same general methods or procedures were used for determining capital costs and indirect costs as were used for the pyrite roasting-acid plant.

Based on 95% recovery of iron in the roasting operation and also on 95% iron recovery (overall) in the reduction roasting-magnetic concentration-sintering operation, the recovered iron would be as is shown in Table III-40, with an assumed 62.4% Fe pellet product.

The capital investment requirements along with operating costs are tabulated in the following Table III-39.

What is the expected value of this type of high grade Fe_2O_3 pellet to the steel mill for blast furnace charge material? It has to be competitive with similar material such as is being produced taconite ores ores and other iron ores in the U.S. and Canadian Great Lakes area and other areas that supply the steel industry located in Illinois, Ohio, and Pennsylvania. The value of the pellets will be influenced by such factors as chemical composition, crushing strength, handling and shipping characteristics, and reducibility. Table III-41 shows the composition range of twelve typical pellets (eight U.S., four Canadian Great Lakes area) as reported by the American Iron Ore Association.

TABLE III-39

Capital Investment and Operating Costs for Calcine Beneficiation

		Plant Capacity 1,000 TPD (98%) Acid 147,200 Short TPY Pellets Millions of Dollars		Plant Capacity 2,500 TPD (98%) Acid 368,000 Short TPY Pellets Millions of Dollars
I. CAPITAL COST DATA				
1. Battery Limit Plant Costs				
A. FluoSolids (DFI) Magnetic Reduction		$ 1.0		$ 1.73
B. Grinding and Magnetic Concentration		$ 1.2		$ 2.08
C. Pelletizing		$ 2.65		$ 4.58
Total		$ 4.85		$ 8.39
2. Total Plant Cost (Battery Limit Cost x 1.18) (18% for Offsites)		$ 5.72		$ 9.9
3. Total Capital Investment (Total Plant Cost x 1.11) (11% for Construction and Startup Costs)		$ 6.30		$ 11.0
II. DIRECT OPERATING COSTS				
1. Labor				
A. Direct Operating Labor - Mandays/24 hour day		27		27
Cost at $4/Manhour - Dollars/Ton Pellets		$ 2.14		$ 0.86
B. Direct Maintenance Labor - Mandays/24 hour day		13		13
Cost at $4/Manhour - Dollars/Ton Pellets		$ 1.03		$ 0.41
Total Direct Operating and Maintenance Labor - Dollars/Ton Pellets		$ 3.17		$ 1.27
2. Power	KWH/Ton Pellets			
FluoSolids (DFI) Reduction	6.0			
Grinding & Magnetic Concentration	27.0			
Pelletizing	50.0			
Total	83.0			
Cost at 0.8¢/KWH - Dollars/Ton Pellets		83 $ 0.66	83 x 90% =	75 $ 0.59
3. Fuel	Million Btu/Ton Pellets			
FluoSolids (DFI) Reduction	1.25			
Pelletizing	1.0			
Total	2.25			
Cost at 40¢/million Btu - Dollars/Ton Pellets		2.25 $ 0.90	2.25 x 90% =	2.025 $ 0.81
4. Water (Cooling and Process) - Gallons/Ton Pellets		750		750
Cost at 5¢/1000 gallons		$ 0.04		$ 0.04
5. Bentonite for Binder - Pounds Bentonite/Ton Pellets		12		12
Cost at 1.5¢/pound Bentonite - Dollars/Ton Pellets		$ 0.18		$ 0.18
6. Maintenance Materials and Supplies				
A. FluoSolids (1.5% annually of Total Plant Cost)				
B. Grinding & Magnetic Concentration (3% annually of Total Plant Cost)				
C. Pelletizing (2% annually of Total Plant Cost)				
Cost - Dollars/Ton Pellets		$ 0.83		$ 0.58
Total Direct Operating Cost - Dollars/Ton Pellets		$ 5.78		$ 3.47
III. INDIRECT OPERATING COST				
1. Labor Overhead (100% of Direct Operating Labor) - Dollars/Ton Pellets		$ 2.14		$ 0.86
2. Taxes and Insurance, Interest on Working Capital, Plant Depreciation (12.3% annually of Total Capital Investment) - Dollars/Ton Pellets		$ 5.35		$ 3.74
Total Indirect Operating Cost - Dollars/Ton Pellets		$ 7.49		$ 4.60
IV. CREDIT FOR SUBSTITUTION OF SMALL TAILINGS DISPOSAL SYSTEM FOR MAGNETIC CONCENTRATING PLANT FOR A LARGE CALCINE DISPOSAL SYSTEM				
Credit - Dollars/Ton Pellets		- $ 0.08		- $ 0.08
Total Processing Cost - Dollars/Short Ton Pellets		$ 13.19		$ 7.99
Short Tons Pellets/Ton (98%) Product Acid				
Plant Type I - 0.447				
Plant Type II = 0.43				
Total Processing Cost - Dollars/Ton (98%) Product Acid				
Plant Type I		$ 5.90		$ 3.57
Plant Type II		$ 5.67		$ 3.44

TABLE III-40

RECOVERED IRON

	Plant Type I	Plant Type II
Pounds Fe/Ton (98%) Acid-From Roasting	585	565
Pounds Fe in High Grade Fe_2O_3 Pellets/Ton (98%) Acid	556	537
Pounds Pellets/Ton 98% Acid (62.4% Fe in Pellets)	892	862

Annual Pellet Production
Short Tons Pellets (330 day year)

Acid Plant Capacity-TPD Acid Plant Type I	Acid Plant Capacity-TPD Acid Plant Type II	I	II
1,000	1,033	147,200	146,900
2,500	2,583	368,000	367,250

TABLE III-41

ANALYSES OF GREAT LAKES AREA PELLETS
(Natural Basis)

Component	Range	Average
Iron (Natural)	60.3 to 65.0%	62.4%
Phosphorus	0.01 to 0.067	0.028
Silica (SiO_2)	5.3 to 8.6	7.4
Alumina (Al_2O_3)	0.2 to 1.9	0.9
Manganese	0.01 to 0.4	0.2
Lime and Magnesia	0.1 to 0.9	0.6
Sulfur	0.003 to 0.015	0.005
Moisture	0.7 to 3.0	1.8

The current quoted price for Lake Superior iron ore pellets is 25.2 cents per natural iron unit. For a pellet material of 62.4% natural iron content the quoted price is $15.70 per long ton (2240 pounds) delivered to lower lake ports, in the hold of the vessel. The shipping charges from the point of production to the lower lake ports range from a low of $2.50 to a high of $3.75 per long ton, with an average of $3.04/long ton. Based on the quoted price of $15.70/long ton at lower lake ports and an average shipping charge of $3.04/long ton, the quoted value at the producer's plant would be $12.66/ long ton at 62.4% natural iron pellet or $11.30 per short (2000 lb) ton.

Railroad transportation charges from the lower lake ports to the various points of consumption in Ohio, Illinois, Pennsylvania, and Kentucky range from $2.08 to $4.04/long ton. Also, dock charges at the lower lake ports amount to $0.71/long ton on a yearly basis. At an average railroad shipping charge of $2.65/long ton, the quoted value at the point of consumption would be $15.70 + $0.71 + $2.65 = $19.06 per long ton or $17.00/short ton of pellets of 62.4% natural iron content.

Some of the pellet-producing plants in Minnesota, Michigan, and Wisconsin are so located as to be able to ship direct by railroad to the consumer. The rail shipping charges in these cases amount to from $2.80 to $4.00/long ton. Again based on a quoted value of $12.66/long ton at the point of production, the quoted value at the point of consumption would range from $15.46 to $16.66/long ton or $13.70 to $14.90/short ton of pellets of 62.4% natural iron content.

We wish to emphasize that all the above prices as to the value of the iron-ore pellets and the transportation charges are quoted prices. We understand that effective prices for pellets can be significantly below the quoted price given above - about $0.19 - 0.21 per iron unit instead of $0.252. The actual price one could expect to obtain from a consuming steel company would be subject to negotiations based upon the value of the product to the company, and would depend upon many factors including pellet analyses and strength, reducibility, pellet-producing capacity, and certainly the needs of the potential customer. Likewise the transportation charges would be subject to negotiations and would depend upon pellet plant location and plant capacity.

Based on the total processing cost of $13.19/short ton of pellets for a 1000-tons-per-day acid plant, the beneficiation of the pyrite calcine would be a money-losing venture. For a 2500-tons-per-day acid plant the estimated total processing cost of $7.99/short ton of pellets could constitute a small credit to the acid producing facility. However, because of the large total capital investment of $11 million for the calcine beneficiation facility, the return on investment could not be expected to be very attractive. A pellet plant capable of producing 368,000 tons per year is, by today's standards, a small plant, incapable of achieving the economics of scale associated with larger plants (i.e., one million tons per year and larger) and is unlikely to obtain favorable long-term contracts.

Accordingly, we believe that any benefit to a pyrite-based acid plant which might be obtained through the sale of by-product iron values would most likely occur by selling the iron calcines, either as a sinter strand feed or possibly for direct injection into the blast furnace tuyeres.

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IV. SULFURIC ACID MARKET

A. UNITED STATES

1. Production and Shipments

In 1966, sulfuric acid production in the United States amounted to 28.5 million tons (100% H_2SO_4) as reported by the U.S. Department of Commerce. The estimated production by regions of the United States (see Figure IV-1) is shown in Table IV-1; we have also estimated the breakdown between virgin (new) and spent (refortified) acid production.

The disposition of sulfuric acid produced in 1966 is also estimated in Table IV-1. Although Government sources do not report in this manner, we were able to estimate in-plant consumption by regions, based on the shipments as reported for the various states. As this table clearly shows, the largest production and in-plant consumption is in the South Atlantic region; this sulfuric acid is largely used for the production of phosphoric acid for use in fertilizers.

Though the largest production is in the South Atlantic region, largest shipments are in the West South Central region. This in part reflects a large merchant demand for sulfuric acid for petroleum refining in Texas and Louisiana and also the shipment of by-product acid from smelting operations.

Shipments of acid account for roughly half of acid disposition, but only minor amounts of sulfuric acid move over long distances, either within or between regions. Sulfuric acid is a low-cost commodity, and with a merchant price in the range of $15-25 per ton f.o.b. plant, is not usually competitive when

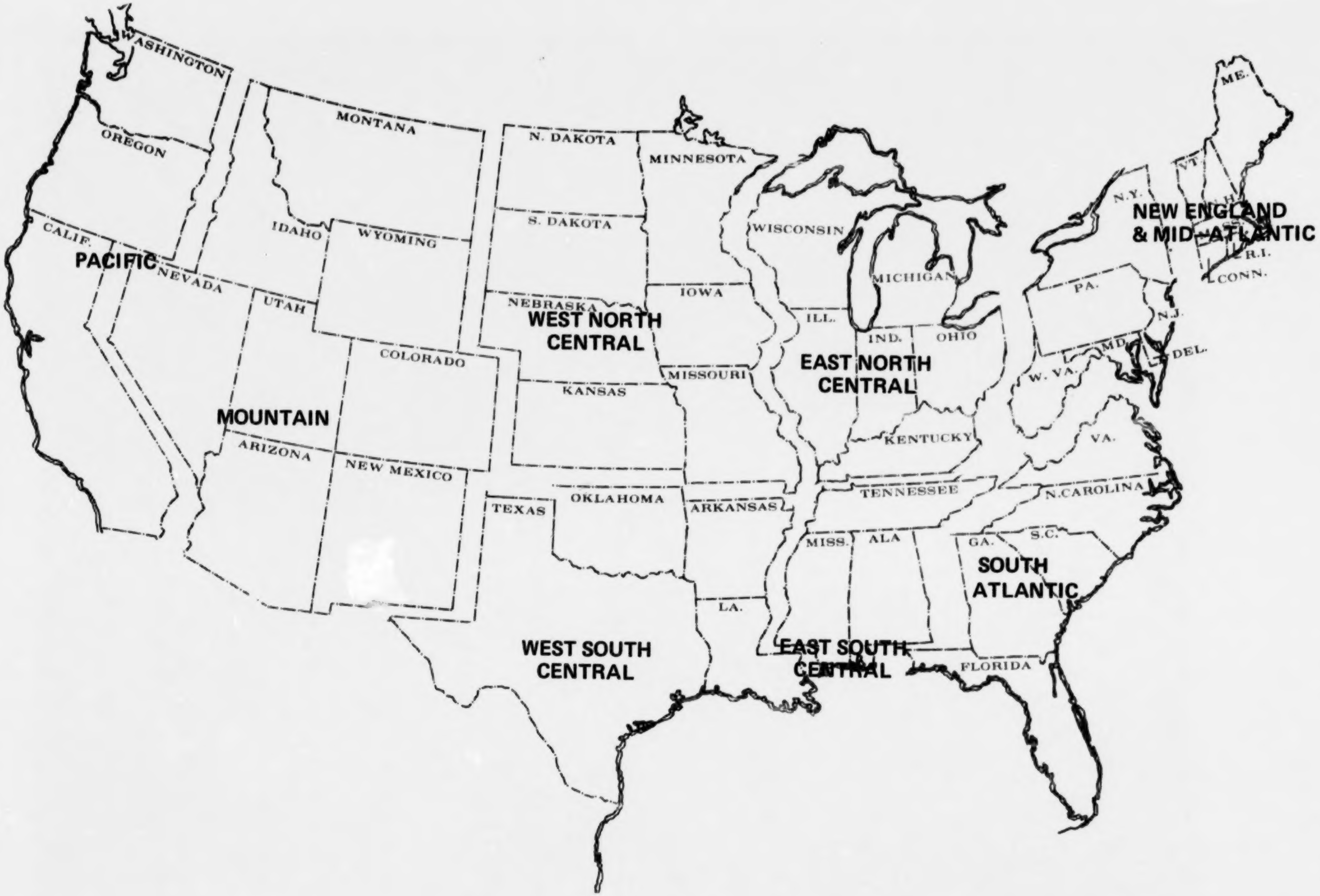

FIGURE IV–1 REGIONS OF THE UNITED STATES

TABLE IV-1

ESTIMATED REGIONAL PRODUCTION AND DISPOSITION OF SULFURIC ACID, 1966

(thousands of short tons)

	Production			Disposition		
	New	Refortified	Total	In-Plant	Shipments	Total
New England	205	0	205	95	110	205
Middle Atlantic	3770	260	4030	1487	2543	4030
South Atlantic	9030	0	9030	6791	2239	9030
East North Central	3372	158	3530	1414	2116	3530
West North Central	1103	32	1135	781	354	1135
East South Central	1877	25	1902	514	1388	1902
West South Central	4792	304	5096	1632	3464	5096
Mountain	1834	57	1891	1052	839	1891
Pacific[1]	1523	135	1658	581	1077	1658
Total	27,506	971	28,477	14,347	14,130	28,477

Capacity 1/1/67	34,652
% Operating Rate	82%

1. Includes one plant in Hawaii

Source: Arthur D. Little, Inc. estimates, based on U. S. Department of Commerce production and shipments reports.

freight charges exceed \$3-4 per ton. Its shipment, therefore, is restricted to within approximately 100-200 miles of the plant where produced. There are a few major exceptions to this rule; for example, the Tennessee Corporation plant at Copper Hill, Tennessee, ships acid up to 600-800 miles, since it is a by-product acid producer and must dispose of its output. In competitive situations, Tennessee Corporation may be forced to absorb the additional freight.

2. Consumption

Sulfuric acid distribution by end use for the years 1963, 1964, and 1965, as estimated by the Bureau of Defense Services Administration, U. S. Department of Commerce, is shown in Table IV-2. Our own estimates for 1966 are also shown. As can be seen, phosphate fertilizer (including phosphoric acid, normal superphosphate, and ammonium phosphate sulfates) is by far the largest end use, accounting for 41% of the total. An additional 528,000 tons (included in other chemicals) was used in the manufacture of mixed fertilizers (containing N, P_2O_5, and K_2O).

Other major uses for sulfuric acid include production of ammonium sulphate, petroleum refining and sulfonation of petroleum additives, the production of titanium dioxide for paint pigments, and iron and steel pickling. Ammonium sulfate (largely used for fertilizer) accounts for about 7%, titanium dioxide 6%, and iron and steel pickling 4% of the estimated total sulfuric acid consumed.

TABLE IV-2

SULFURIC ACID DISTRIBUTION BY END USE
(thousands of tons, 100% H_2SO_4)

	1963	1964	1965	1966	% of Total
Phosphate Fertilizers	6906	7753	9275	11675	41%
Ammonium Sulfate	1390	1759	1967	1885	7
Titanium Dioxide	1951	1975	1900	1740	6
Petroleum - Alkylate Refining	1325	1375	1400	1435	5
Petroleum - Other uses[1]	1130	1205	1260	1335	5
Iron and Steel Pickling	1084	1190	1075	1000	3
Hydrofluoric Acid	603	630	710	785	3
Rayon and Cellophane[2]	839	885	895	836	3
Alcohols	599	631	665	700	2
Aluminum Sulfate	536	574	580	592	2
Synthetic Detergents	481	500	510	530	2
Copper & Uranium Leaching and Processing	607	576	567	550	2
Dyes and Intermediates	294	312	330	350	1
Explosives[3]	146	118	100	198	1
Other Chemicals	2697	2951	3099	3389	12
Exports	7	14	7	-	
Miscellaneous	1165	1302	1360	1500	5
Total	21,760	23,750	25,700	28,500	100%

1. Includes sulfonated petroleum lube oil additives and other petroleum products.
2. Includes other cellulose film, sheets, or products.
3. Excludes mixed acid, which is included in other chemicals for 1963, 1964, 1965.

Source: U.S. Department of Commerce, 1963-65.
Arthur D. Little, Inc. 1966

Petroleum refining uses substantial quantities of sulfuric acid, both by itself and with hydrofluoric acid. Together, these uses accounted for over 3.5 million tons of sulfuric acid in 1966, or more than 12% of the total.

An analysis of the growth in the major sulfuric acid end-use areas is shown in Table IV-3. Use in phosphate fertilizers exhibits the most favorable rate of growth, approximately 12% per year, largely due to recent increases in phosphoric acid production. Consumption of phosphate fertilizers in the United States (4.3 million tons P_2O_5 in year ending June 30, 1967) has increased at the rate of about 6% per year over the last ten years; exports accounted for an estimated 498,000 tons P_2O_5, or about 8% of production in 1966 and are expected to increase only nominally. However, nearly 900,000 tons P_2O_5 was added to inventory in 1966, and similar amounts were added in 1967. Overall, we believe phosphate fertilizer production will demonstrate a lower growth rate (on the order of 4% per year) during the next five years, as this inventory must be disposed of. However, phosphate demand varies by region, and production in the midwest could increase at a higher rate (8-10% per year) to satisfy the requirements in that region.

The production of ammonium sulfate remained rather constant for the five-year period between 1958 and 1963 but increased substantially from 1963 to 1966. We expect the production of ammonium sulfate to continue to increase at about 5% per year over the next several years.

Titanium dioxide production by the sulfate process is expected to remain constant or decline slightly in the future. Other competitive methods appear to be responsible.

TABLE IV-3

GROWTH IN MAJOR SULFURIC ACID END USES, UNITED STATES

(thousand of tons, H_2SO_4)

	1958	1960	1963	1965	1966	Growth Rate (%/yr) Historical	Projected to 1972
Phosphate Fertilizers	4825	5575	6906	9275	11,675	12 %	4-5%
Titanium Dioxide	1375	1500	1951	1900	1740	2-3%*	0
Ammonium Sulfate	1325	1200	1390	1967	1885	5%	5%
Iron & Steel Pickling	750	900	1084	1075	992	0*	--
Rayon & Cellophane	650	700	839	895	836	3%	--
Petroleum Refining	n.a.	n.a.	2455	2660	2770	4%	4%

* Actual use declined in last few years

Sources: U. S. Department of Commerce; Arthur D. Little, Inc., estimates for 1966

Sulfuric acid pickling of steel is now declining slightly in favor of other processes, and future declines can be expected. These declines may be steep as the industry makes rapid changeovers to the new processes.

The production of rayon and cellophane has increased slightly over the past several years but will decline in the future. Competition from other synthetic fibers and plastic films has imposed low returns on the cellulosic fiber and film industry, and no new plants are being built.

Sulfuric acid consumed directly in petroleum refining accounted for 2.8 million tons in 1966, and use is increasing at the rate of 4% annually. Production of refinery alkylate for high-octane gasolines has been largely responsible, but the sulfonation of lube oils and petroleum additives is expected to provide the most attractive future growth area.

3. Sulfur and Sulfuric Acid Prices

A summary of prices reported by the U.S. Department of Commerce is shown in Table IV-4. Since different prices are reported for shipments of acid made by the contact and chamber processes, we have shown these separately. Price differences are also noted between commercial shipments and interplant transfers.

Prices for total shipments of both "kinds" of acid declined steadily between 1961 and 1964 but began to recover in 1965 and were higher again in 1966. The effects of recent sulfur price increases can be seen; sulfur was listed as low as $23 per ton, spot basis, in 1963 and 1964, and even lower prices were reported on long-term contracts. In 1966, however, sulfur prices were sharply

TABLE IV-4

SULFURIC ACID VALUES
(thousands of tons H_2SO_4)

	Commercial Shipments		Interplant Transfers		Total Shipments	
	Tons	$/ton	Tons	$/ton	Tons	$/ton
Gross, Total						
1966	12740	17.31	1390	18.57	14130	17.44
1965	11823	16.64	1366	17.96	13189	16.77
1964	10992	16.60	1381	17.65	12373	16.72
1963	10206	17.01	1258	17.74	11464	17.09
1962	9757	17.46	1142	18.24	10899	17.54
1961	8911	17.81	942	18.18	9853	17.84
Contact, Gross						
1966	12484	17.27	1281	18.29	13765	17.37
1965	11580	16.61	1230	17.38	12810	16.68
1961	8332	17.98	844	17.65	9176	17.95
Chamber						
1966	256	19.21	110	21.63	366	19.94
1965	242	18.19	137	23.06	379	19.95
1961	580	15.23	98	22.73	678	16.31

Source: U.S. Department of Commerce

higher, and the trend continued in 1967. In December 1967, domestic sulfur prices were $38 per long ton for "dark" sulfur and $39 for "bright" sulfur, f.o.b. Gulf Coast producing points. (These prices were raised to $41 and $42, respectively, on March 1, 1968.) Supplies are limited, and many sulfuric acid plants have had difficulty obtaining sufficient supplies at list prices.

The 1967 f.o.b. list price for 98% acid in tank cars was $32.75 per short ton (Oil, Paint and Drug Reporter, December 18, 1968). Yet, assuming sulfur at $42.00 per long ton delivered ($38.00 per long ton f.o.b. plus freight to a distant point), we estimate sulfuric acid production costs to be approximately $14.85 per short ton (see Table V-3 for detailed calculations). By allowing for a pre-tax return on investment of 20% for a 1500-ton-per-day acid plant, the total cost rises to $17.05, far short of the December, 1967, list price of $32.75 per ton. With such a spread -- in this example, $15.70 per short ton -- it's reasonable to suppose that sulfuric acid prices vary considerably, and this is in fact the case.

Among the factors affecting sulfuric acid prices are raw material costs and availability, production costs, shipping distances, required rates of return, volumes produced, method of production, purity and grade, demand for acid versus available supply, volumes purchased by customers, purchase frequency, reprocessing requirements, whether the acid is to be used captively or by outside customers, and, if the latter, contractual arrangements.

Definitive and exact price data are considered confidential information by both producers and buyers, and are therefore extremely difficult to obtain. Generally speaking, however, there are four price categories for sulfuric acid, defined primarily on the basis of the volumes of acid purchased and whether the use is captive or merchant. These categories are as follows (price ranges based on acid cost of $14.85 per ton, list price of $32.75 per ton):

I	$15-20/ton	captive use, large volumes
II	$18-22/ton	long term, large volume, merchant contract sale, including acid freight
III	$20-27/ton	smaller volume, merchant contract sale, including acid freight
IV	$27-up/ton	spot merchant sales including acid freight

Except for captive use, the majority of acid sales are included in categories II and III, with average merchant prices being on the order of $20-26 per ton. We believe this price range is generally typical of those in the eight-state area considered in this report.

Obviously, the sharp increase in acid prices is due to factors other than just the higher price of sulfur, since the 0.336 ton required to make a ton of acid cost about $6.90 in 1964, but in 1967 cost $11.50, or about $4.60 more per ton of acid. Aside from higher manufacturing costs, one factor is that producers have probably taken this opportunity to obtain a more satisfactory return. We suspect another reason is that acid producers are paying premiums for imported sulfur to maintain satisfactory production rates in the face of reduced domestic sulfur supplies.

At present, the major U.S. Frasch sulfur producers (Texas Gulf Sulfur and Freeport Sulfur) have placed their customers on allocated supplies, The allocations usually being a certain percentage -- as low as 65% -- of shipment in 1965. These allocated shipments are the result of a sulfur shortage caused principally by a surging demand for the material by the fertilizer industry. Since 1963, sulfur demand has exceeded production, and producers have been required to supply the excess from inventory. These domestic inventories have been depleted considerably. The shortage has not only caused domestic sulfur prices to rise; Mexican Frasch sulfur is being sold for as much as $50 per long ton, and some Canadian by-product sulfur (from natural gas stripping) is commanding similar or higher prices.

The combination of a shortage of sulfur and increasing prices has had other results than merely to increase acid prices. It has also intensified interest in obtaining new sulfur supplies and/or developing new processes which are less dependent upon the use of sulfur or sulfuric acid. Sulfur sources or alternative projects heretofore considered uneconomic are being examined in detail, because present sulfur prices have improved their economics. Exploration for new sulfur deposits has surged ahead over the past three years. The following are among the projects in North America which are underway or being considered to make available, directly or indirectly, additional sulfur or sulfur values:

United States

- Reactivation of Frasch mines on the Gulf Coast
- Development of new sulfur deposits in West Texas
- Installation of New sulfur production process based on gypsum in West Texas

- Recovery of sulfur from crude oil and natural gas
- Production of sulfuric acid from western pyrite sources
- Production of sulfuric acid from gypsum
- Increased production of "furnace acid" (i.e., phosphoric acid from elemental phosphorus) for use in fertilizer manufacture, thereby eliminating use of sulfuric acid
- Recovery of sulfur values from SO_2 in stack gases
- Use of nitric acid instead of sulfuric acid to produce phosphatic fertilizers

Mexico

- Exploration for new sulfur deposits (eight or more individual projects)

Canada

- Expansion of sulfur recovery from sour gas production in western Canada
- Recovery of sulfur from tar sand oil production in Athabaska
- Recovery of sulfur or sulfur values from smelting operations

In addition to the above programs, exploration for new sulfur supplies in other parts of the free world has been increasing; the most significant result thus far has been the negotiations for concessions in the Mishraq area in northern Iraq. A number of desulfurization projects involving natural gas and crude oil are also being closely evaluated.

At the present time, it is too early to know what impact some or all of these and other projects will have on the supply of sulfur; some will undoubtedly be abandoned or deferred, while others will be successful. Timing is another unknown; the rate at which new supplies will become available is uncertain.

In the course of our field work we have had the opportunity to talk with a number of industry personnel familiar with the sulfur industry. The prevailing sentiment among these individuals is that it is unlikely sulfur prices will rise beyond \$45-\$50 per long ton over the next five years, and that thereafter prices will probably decline due to the development of new sulfur sources and/or processes which reduce the need for that material. The expected level which prices will eventually reach is thought to be no lower than \$35 per long ton.

The reasoning behind this sentiment is that present price levels offer sufficient incentive for energetic pursuit of new possibilities, some of which are expected to become commercial at current or slightly higher prices. This type of situation, therefore, will tend to limit further price increases.

Thus, the five-year outlook for sulfur and sulfuric acid prices is generally favorable in view of the sulfur shortage. During this period we expect prices to remain firm or increase moderately. Beyond 1972, increasing downward pressure on sulfur prices -- and therefore acid -- will be felt.

B. SPECIFIC MARKETING AREAS CONSIDERED

1. States Included and Consumption by End Uses

Based on the principal areas where pyrite-bearing coals are found, we have selected several points where sulfuric acid plants could be located, assuming feasibility of pyrite delivery to the sulfuric acid plant and disposal of the by-product calcines. The areas we have selected include Pittsburgh, Pennsylvania; Cairo, Illinois-Paducah, Kentucky; St. Louis, Missouri; and Chicago, Illinois. When the 100-200 mile (average 150) shipment limitation is imposed, then these areas include major markets in eight states, including Pennsylvania, Ohio, Illinois, Indiana, West Virginia, Kentucky, Tennessee, and Missouri, and small portions of Iowa and Wisconsin. In order to look at this general market area, we have first estimated the total consumption by end use in the eight states and show this in Table IV-5. These data include total consumption in the eight states and differ from data in later tables, which refer only to markets within 150 miles of production points.

The largest end use for sulfuric acid in these eight states, as it is nationally, is for fertilizers, which consumed 2.1 million tons (40% of total consumption) of sulfuric acid in 1966, two-thirds of which was in Illinois. Ammonium sulfate production consumed nearly one-half million tons of sulfuric acid, the largest amount consumed in Pennsylvania. The production of sulfonated synthetic detergents is fairly equally distributed in five states out of the eight. Titanium dioxide is produced in only one plant, near St. Louis, Missouri. We believe this plant to be operating at or near capacity and do not expect further increases.

TABLE IV-5

ESTIMATED SULFURIC ACID END-USE PATTERN IN SELECTED STATES, 1966

(thousands of short tons 100% H_2SO_4)

	Pa.	Ohio	Ill.	Ind.	W.Va.	Ky.	Tenn.	Mo.	Area Total	Projected Average Annual Growth Rate
Fertilizers	18	93	1532	47	--	25	126	284	2125	8-10%
Ammonium Sulfate	199	69	28	88	110	15	--	--	509	3
Synthetic Detergents	27	75	30	50	--	--	--	39	221	0*
Titanium Dioxide	--	--	--	--	--	--	--	410	410	0
Aluminum Sulfate	18	28	12	--	--	--	30	30	118	4
Iron & Steel Pickling	142	80	9	105	--	10	--	--	346	0
Rayon & Cellophane	107	--	--	--	150	--	132	--	389	0
Refineries	103	50	102	103	--	--	--	17	375	2
Hydrofluoric Acid	--	30	38	--	40	55	--	--	163	4
Other Uses	146	152	63	23	8	25	50	17	484	5
Total	760	577	1814	416	308	130	338	797	5140	

* Future growth will be in SO_3 sulfonation.

2. Supply-Demand Pattern

Based on the estimated regional production data presented elsewhere, and estimated consumption, we have arrived at a supply-demand balance for each of the eight states in 1966, as shown in Table IV-6. Five of these states had surplus production, and deficits in the remaining three were not large enough to consume all the area's production. On an overall basis, the eight states' net production of sulfuric acid exceeded demand by 845,000 tons. However, the capacity to produce new acid, as of January 1, 1967, was substantially less than demand in three states, Illinois, Missouri, and West Virginia.

C. MAJOR USES OF SULFURIC ACID-TECHNICAL CONSIDERATIONS*

1. Iron and Steel Pickling

Before a metal surface can be made receptive to an additive finish (such as galvanizing or tin plating) or before it can be subjected to further metallurgical processing, oxide scales must be removed. Practically all steel plate, strip, wire, and in general all hot-rolled products must be treated for scale removal before final processing. Normally, three methods or combinations of these are used for scale removal: breaker rolls, shot blasting, and acid pickling. The first two methods are mechanical but normally require a final rinse with acid in order to complete the process. In large strip mills, small breaker rolls are often used in conjunction with pickling baths. Pickling

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*Fertilizers are discussed separately in Chapter V due to their significance in the overall sulfuric acid consumption pattern.

TABLE IV-6

SULFURIC ACID SUPPLY-DEMAND SITUATION IN SELECTED STATES, 1966

(thousands of tons 100% H_2SO_4)

	Estimated Production	Estimated Consumption	Surplus (Deficit)	Capacity to Produce New Acid 1/1/67
Pennsylvania	966	760	206	1040
Ohio	689	577	112	865
Indiana	677	416	261	695
Illinois	1763	1814	(51)	1835
West Virginia	155	308	(153)	156
Kentucky	230	130	100	220
Tennessee	955	338	669	194
Missouri	550	797	(247)	595
Sub-total	5985	5140	845	6320
Other States	22,492	23,330	(815)	28,332
U.S. Total	28,477	28,470	30	34,652

Source: Arthur D. Little, Inc. estimates itself involves immersion of the steel in a dilute solution of acid (usually sulfuric or hydrochloric) at elevated temperatures of 150°-200°F. Pickling can be done at room temperatures, but so doing requires considerably more time.

Historically, sulfuric acid has been the most widely used pickling agent. The fresh acid, of water-white quality and strength of 60 or 66 degree Baumé (77-93% H_2SO_4) is diluted to a 15-25% concentration and heated. In large mills where continuous pickling processes are used, the fresh diluted acid is fed into the top of a series of tanks and cascades down through two or more tanks to the bottom. Steel is introduced into the bottom tank first, and is worked progressively up to the top tank. The name given to this is the cascade process, since the acid "cascades" downward into the baths below. The contaminated acid is drawn off the bottom bath after it has reached a concentration of 8-15% H_2SO_4 and a ferrous sulfate content of approximately 20%. A number of attempts have been made to re-process this contaminated acid, but to date, none have proven to be practical. Therefore, most steel mills react the acid with lime, or in recent years have disposed of the acid in deep wells.

Consumption of sulfuric acid depends substantially on the steel product. Hot-rolled sheet and strip, for example, may consume up to 40 pounds H_2SO_4 per ton, by far the largest use made of sulfuric acid for pickling. Tube, pipe, and bar steel, however, require only about three pounds per ton, since the weight to surface area ratio is substantially less. Wire, on the other hand, requires about 50 pounds H_2SO_4 per ton, since the weight to surface area ratio is much greater. On an overall basis, we estimate that average consumption in pickling is about 40 pounds H_2SO_4 per ton of hot-rolled product pickled, since the hot-rolled sheet and strip is by far the largest portion of the steel output.

A summary of sulfuric acid demand by steel mills in the eight states is shown in Table IV-7.

Recently, a number of steel mills have installed hydrochloric acid pickling equipment. This is done for two reasons, economics and acid disposal problems. The process is essentially the same as with sulfuric acid, but the difference is that the acid can economically be reclaimed for re-use, and in at least one case, McLouth Steel of Detroit, the spent acid can be sold to a chemical company which in turn reclaims the ferric chloride for use as coagulant for water and waste water treatment.

On an operating basis, the net cost of pickling steel with sulfuric acid and neutralizing the waste liquor with lime is about $2.93 per ton of steel. With an acid recovery system, the cost is about $2.81 per ton of steel; the difference is not enough to pay for the recovery unit. With hydrochloric acid, however, the net cost is about $2.61 per ton of steel or approximately a 30-cent-per-ton advantage. Most new steel plants are installing the hydrochloric acid pickling units, and some old plants are changing over. This trend could be reversed with a fall in the price of sulfuric acid: the figures cited above were

TABLE IV-7

SUMMARY OF H_2SO_4 USAGE FOR PICKLING OF CARBON STEEL IN SELECTED STATES

State	1967 H_2SO_4 Consumption (tons)
Indiana	105,000
Illinois	9,000
Ohio	80,000
Pennsylvania	142,000
Kentucky	10,000
West Virginia	- -
TOTAL	346,000

Note: Little steel is made in Missouri, Arkansas, or Tennessee.

Source: Arthur D. Little, Inc., estimates.

based on sulfuric acid at $22 per ton, 93% H_2SO_4, and $30 per ton for 31.5% HCl. Current prices for HCl are in the neighborhood of $16-$20 per ton versus $20-$27 per ton for sulfuric.

We believe that the use of hydrochloric will gradually increase in steel pickling with corresponding decrease in the use of sulfuric acid. It is difficult, if not impossible, to accurately forecast how rapidly this changeover will occur, since it depends on a decision by steel companies to invest in the new facilities required for the hydrochloric acid method. However, in about the last five years, some 14 steel mills out of the 20 major steel mills located in the Pennsylvania-Illinois area have made some move toward a changeover. One of these mills has gone back to sulfuric acid because of fume problems, but others report full satisfaction with the shift. We believe, therefore, that the trend toward hydrochloric acid pickling will continue, but probably some 20-25% of steel will still be pickled with sulfuric acid over the long term. Comparative economics can affect this outlook; should sulfuric acid prices decline with increasing supply, then some companies, which have made the change to hydrochloric but which still retain their sulfuric facilities and capability, could change back. We do not believe that this will occur before the mid-1970's, if then.

Iron and steel pickling represents a major end use in the area at present but can be expected to decline somewhat in the future. A number of steel producers have indicated their intentions of changing over to hydrochloric acid, and some have already done so but not completely. A list of steel producers in the area, their method of pickling, and estimated sulfuric acid consumption in 1967 is shown in Table IV-8. Based on these indicated plans, we estimate that a reduction of 68,000 tons of sulfuric acid can be expected by 1969 and a further reduction of 68,000 tons by 1970.

2. Petroleum Refining

In petroleum refining, sulfuric acid or hydrofluoric acid is used in the manufacture of alkylate, a major component of aviation gasolines and high-octane motor fuels. Alkylation essentially involves the reaction of an olefin feed (such as butylene) with isobutane over a catalyst (the acid) to increase the percentage of iso-octane in the product. Iso-octane is the major ingredient used to upgrade gasolines to the high-octane needed for aviation gasoline; the very large increases in demand for this product during World War II caused the Government to build a number of catalytic units for manufacturing alkylate. During the Korean War, another increase in aviation gasoline requirements occurred, causing further increase in alkylate refining capacity. In about 1955, the production of high-compression engines in automobiles became commonplace, even further increasing the demand for iso-octane.

The increased use of jet-engine aircraft has reduced the demand for high-octane aviation gasoline, and increased production of compact cars with lower-compression engines has also reduced the requirements for high-octane motor fuels. As a result, refinery alkylate capacity has increased only moderately over the past three years. As of January 1, 1964, total United States alkylation

TABLE IV-8

MAJOR STEEL MILLS AND ESTIMATED SULFURIC ACID DEMAND

(Indiana, Illinois, Ohio, Pennsylvania,
Kentucky, and West Virginia)

Mill	Hot Strip Capacity (MM T)	Pickling Potential HCl (1967)	Pickling Potential H_2SO_4 (1967) (tons)
INDIANA			
Bethlehem Steel (Burns Harbor)	?	none (will convert to HCl by 1969)	16,000
Inland Steel (East Chicago)	3.7	50%	26,000
Youngstown (East Chicago)	2.0	none	28,000
U. S. Steel (Gary)	3.3	25% (will be 100% by early 1969)	35,000
Subtotal			105,000
ILLINOIS			
Acme Steel (Chicago)	0.8	probably none	6,000
Granite City Steel (Granite City)	1.4	near 100%	3,000
Subtotal			9,000
OHIO			
Armco Steel (Middletown)	2.0	going to HCl	28,000
Detroit Steel (Portsmouth)	1.2	about to go	17,000
Jones & Laughlin (Cleveland)	1.6	50%	11,000
Republic Steel (Warren)	2.1	high to 100% (regeneration)	20,000
Republic Steel (Cleveland)	2.5	50%	

TABLE IV-8 (Continued)

MAJOR STEEL MILLS AND ESTIMATES SULFURIC ACID DEMAND (cont'd)

Mill	Hot Strip Capacity (MM T)	Pickling Potential	
		HCl (1967)	H_2SO_4 (1967) (tons)
Wheeling Steel (Steubenville)	1.4	near 100%	4,000
Youngstown S & T (Campbell)	2.5	100%	-
Subtotal			80,000
PENNSYLVANIA			
Bethlehem Steel (Johnstown)	?	none	6,000
Jones & Laughlin			
(Aliquippa)	1.6	none	22,000
(Pittsburgh)	1.5	none	21,000
Pittsburgh Steel Co. (Allenport)	0.9	(back to H_2SO_4 fume problem)	12,000
Sharon Steel Corp. (Farrell)	0.9	HCl 75%	3,000
U. S. Steel			
(Fairless Hills)	3.1	20%	35,000
(Dravosburg)	3.1	none	43,000
Subtotal			142,000
KENTUCKY			
Acme Steel (Wilder)	0.4	none	4,000
Armco Steel (Ashland)	0.4	Going to HCl	6,000
Subtotal			10,000
WEST VIRGINIA			
National Steel (Winston)	3.0	100%	-
Total			346,000

capacity was 504,000 barrels per stream day, with about 75% utilizing sulfuric acid as a catalyst. As of January 1, 1967, total alkylation capacity was about 595,000 barrels per day, of which sulfuric acid-type accounted for 423,000 barrels or about 71%. There is, therefore, a slight shift in favor of hydrofluoric acid, but in total, alkylation capacity has increased at about 5-6% annually while sulfuric acid alkylation capacity is growing about 4% annually. The basic reason is that the hydrofluoric acid method allows the production of a somewhat broader range of products and is also slightly less expensive. There is little likelihood that any of the present sulfuric acid units will be converted to hydrofluoric, but the chances are better than even that new units will utilize hydrofluoric acid.

Specifications for the usual type of alkylation-grade sulfuric acid are as follows: 98-99.5% H_2SO_4, SO_2 not to exceed 0.01% by weight; iron content not to exceed a maximum of 0.2% by weight; arsenic not to exceed a maximum of 0.00005% by weight; tin, 0.001% by weight; lead, 0.005%; and sediment 0.02% by weight. The acid also must be free of "floaters."

In the alkylation process, only relatively small amounts of sulfuric acid are actually consumed. Various estimates range from 0.2-0.5 pound per gallon of total alkylate produced, or in the range of 8-21 pounds H_2SO_4 per barrel. The acid remaining after alkylation has taken place, however, is diluted by an acid-oil polymer formed by side reactions. This spent or "sludge" acid contains from 85-90% H_2SO_4, depending on whether the cascade or strato alkylation process is used. One of the key requirements of an acid supplier to a petroleum refinery is that he take back the sludge acid for re-processing and allow the refinery credit.

The credit for acid returned to suppliers is normally about 50% of its cost as new acid. The acid producer can recover sulfur values from the acid, but a substantial investment in sludge burners is necessary; in the case of refinery acid which is used further to process oils and lube additives, fairly substantial amounts of hydrocarbons (up to 40% by weight) may become intermixed with the sulfuric acid. Therefore, the acid producer is faced with the problem of disposing of this portion.

A list of refineries in the areas being considered, together with their estimated demand for new sulfuric acid, is shown in Table IV-9. To arrive at an estimated use of sulfuric acid for producing refinery alkylate for gasoline, we have used an average of 15 pounds of H_2SO_4 per barrel of alkylate produced. However, we wish to point out that substantial variation exists between refineries -- as much as 8.8 to 25.2 pounds per barrel. On an overall average, we believe the 15 pounds per barrel figure fairly represents the requirement for sulfuric acid in the area. Net consumption, however, is significantly lower, since sludge-bearing acid is usually returned to the supplier, who supplies fresh acid. Based on interviews with refiners and our own knowledge of the alkylation process and the re-processing of sludge acid, we believe that the net consumption is about 7.2 pounds of H_2SO_4 per barrel of alkylate, or 110,000 tons in the area under consideration.

3. Synthetic Detergents

Sulfuric acid is used in the treatment of hydrocarbon compounds to add the sulfo group (SO_2OH) which gives surface-active properties to the hydrocarbon. The most widely used reagent for this sulfonation process is oleum, a

TABLE IV-9

REFINERIES USING SULFURIC ACID FOR ALKYLATION

Refinery	Location	Capacity (b/sd)	Estimated Sulfuric Acid Consumption (100% H_2SO_4) lbs/day	short tons/day
ILLINOIS				
American Oil	Wood River	5,300	79,500	39.75
Marathon Oil	Robinson	2,600	39,000	18.5
Shell Oil	Wood River	20,000	300,000	150.
Texaco	Lawrenceville	2,500	37,500	18.75
	Lockport	4,400	66,000	33.00
INDIANA				
American Oil	Whiting	15,500	232,000	116.0
Cities Service	East Chicago	4,200	63,000	31.5
Mobil Oil	East Chicago	3,000	45,000	22.5
Sinclair	East Chicago	5,000	75,000	37.5
MISSOURI				
American Oil	Sugar Creek	4,600	64,500	32.25
OHIO				
Standard Oil	Toledo	6,200	93,000	46.5
Sun Oil	Toledo	6,000	90,000	45.0
Union Oil of Calif.	Toledo	1,800	27,000	23.5
PENNSYLVANIA				
United Refining	Warren	1,100	16,500	8.25
				697.25

876.50 x 365 days x 90% = 229,000 tons
Estimated net consumption 110,000 tons

Sulfuric Acid 8.8 to 15.1 lbs/per barrel of alkylate capacity in Kellog process and 12.6 to 25.2 lbs/per barrel in the cascade process. Using an average of 15 lbs/per barrel, we have arrived at the fresh sulfuric acid consumption. However, sludge-bearing acid usually is returned to the acid producer who supplies fresh acid; based on interviews with refiners, we estimate net consumption about 7.2 lbs. 100% H_2SO_4 per barrel. White oil - up to 6 lbs per gallon, 104.5% H_2SO_4.

Source: Capacity and process data from Oil and Gas Journal, April 3, 1967.

form of sulfuric acid which contains additional sulfur trioxide (SO_3). However, detergent products made with oleum have activity in the range of 86-88%, while products made with the newer method of using SO_3 have 96-98% activity. There is, therefore, a shift among producers to the sulfur trioxide route for sulfonation. There are some other advantages: the resulting sulfonate not only has higher activity, but a clear liquid synthetic detergent can be obtained, and there is no problem of disposing of spent acid since the reaction is essentially complete.

The production of sulfated and sulfonated surface-active agents in the United States is believed to have increased significantly since 1960, although exact and comparable data are not available from the U. S. Tariff Commission. The method of reporting these chemicals has changed, and exact comparisons with earlier years cannot be made. Nevertheless, we estimate that the total sulfated and sulfonated products would be in the range of about 1.6 billion pounds in 1966, an increase of approximately 18% over the total in 1962. Of these, the dodecylbenzene sulfonates account for over 500 million pounds, or nearly one-third of the total. The ligno-sulfonates have also grown very rapidly and now account for about 25% of the total.

Industry sources estimate that sulfated and sulfonated detergent production will grow at about 5% a year. However, the industry also estimates that the use of sulfur trioxide will continue to increase at the rate of about 5% of the total. In effect, then, the use of sulfuric acid will probably remain approximately constant, and further increases in sulfonation will be via the sulfur trioxide route. This minimal growth can be seen in the estimate of the

U. S. Department of Commerce distribution of sulfuric acid by end use, where the use of sulfuric acid for synthetic detergents and sodium phosphates increased about 3% per year between 1963 and 1965, while the overall sulfated and sulfonated detergent production increased at an estimated 6%.

The major producers of sulfonated surface-active agents and detergents in the potential producing areas are shown in Table IV-10. We have estimated their consumption of sulfuric acid on the basis of industry comments and our own experience in this area.

4. Ammonium Sulfate

Ammonium sulfate is produced by reacting either synthetic anhydrous ammonia or byproduct ammonia from coke ovens and from other sources with new or virgin sulfuric acid. In 1966, total production was 3 million tons, of which byproduct ammonium sulfate accounted for 2.1 million tons. When coal is heated to produce coke, the off-gas can be utilized as fuel or feedstock only after the naturally-occurring ammonia is removed. Normally, some five or six pounds of ammonia is produced per ton of coal coked. One of the most efficient and economical methods to remove ammonia is to absorb it in sulfuric acid and collect the ammonium sulfate crystals. New or virgin acid is normally used, since the crystal growth can be more accurately controlled and a more desirable physical condition of the end product can be assured. Approximately 0.76 ton of sulfuric acid is required per ton of product.

TABLE IV-10

MAJOR PRODUCERS OF SULFONATED DETERGENTS

Company	Estimated Consumption of 100% Sulfuric Acid (thousand tons/year)
Procter & Gamble	
Chicago, Ill.	16.4
St. Louis, Mo.	16.4
Colgate-Palmolive	
Jeffersonville, Ind.	14.7
St. Louis, Mo.	24.5
Continental Oil	
Chicago, Ill.	6.0
Hammond, Ind.	
Lever Bros.	
St. Louis, Mo.	16.0
Stepan Chemical	
Millsdale, Ill.	-- (uses SO_3)
Richardson Co.	
Chicago, Ill.	-- (uses SO_3)

Source: Arthur D. Little, Inc.

Estimated consumption of sulfuric acid for production of ammonium sulfate was approximately 460,000 tons in 1966. In Table IV-11 we present the major producers of byproduct ammonium sulfate within the potential sulfuric acid producing areas. Nearly all of these produce ammonium sulfate as a byproduct from coke oven operation, although one, Rohm & Haas Co., produces ammonium sulfate as a byproduct in the manufacture of acrylics. There are no producers of ammonium sulfate from synthetic ammonia within the eight-state area.

The future of byproduct ammonium sulfate production is not clear. The amount produced depends principally on the amount of coke produced in the coke ovens, and this, in turn, depends to a large extent on the use of coke in producing steel. Several technological improvements over the past decade have enabled the steel industry to use less coke per ton of steel produced by using more oxygen in the furnaces. This, in turn, results in less production from the coke ovens and a corresponding decrease in the amount of byproduct ammonia produced. Overall, the outlook is for producing less byproduct ammonium sulfate in the eight states, but this cannot be predicted with any degree of certainty. Byproduct ammonium sulfate from sources other than coke ovens, however (e.g., caprolactam, acrylic) could continue to increase, thus tending to offset the effect of declining production from coke ovens.

In our forecast of sulfuric acid consumption, we have indicated approximate 2-3% per year increases in ammonium sulfate production in the eight-state area, based on the demand which exists from fertilizer producers and

TABLE IV-11

MAJOR PRODUCERS OF BYPRODUCT AMMONIUM SULFATE

	Estimated Capacity (thousand tons ammonium sulfate)
Bethlehem Steel Corp.	
Johnstown, Pa.	32
Citizen Coke and Gas Utility	
Indianapolis, Ind.	6
Crucible Steel	
Midland, Pa.	6
Granite Steel	
Granite City, Ill.	6
Inland Steel	
Indiana Harbor, Ind.	40
Interlake Steel	
Erie, Pa. (non operating on stand-by)	4
S. Chicago, Ill.	6
International Harvester	
S. Chicago, Ill.	12
J & L Steel	
Aliquippa, Pa.	22
Pittsburgh, Pa.	25
National Steel	
Weirton, W. Va.	10
Pittsburgh Steel	
Monessen, Pa.	9

TABLE IV-11 (Continued)

	Estimated Capacity (thousand tons ammonium sulfate)
Republic Steel	
Chicago, Ill.	6
Cleveland, Ohio	30
Massillon, Ohio	2
Warren, Ohio	6
Youngstown, Ohio	15
Rohm & Haas	
Louisville, Ky.	20 acrylic byproduct
Sharon Steel	
Fairmount, W. Va.	6
Shenango, Inc.	
Pittsburgh, Pa.	6
U. S. Steel	
Clairton, Pa.	110
Fairless, Pa.	13
Gary, Inc.	75
Lorain, Ohio	22
Joliet, Ill.	7
Wheeling Steel	
Follansbee, W. Va.	20
Youngstown Sheet & Tube	
Campbell, W. Va.	110
Total	626

All these plants use 100% virgin acid except Armco Steel in Middletown, Ohio, in which 14% is spent acid. Estimated maximum sulfuric acid use:

$$626,000 \times 0.76 = 475,000 \text{ tons } H_2SO_4$$

Source: Arthur D. Little, Inc., estimates.

farmers for the product. Since we expect byproduct ammonium sulfate production to decline slightly or remain about level, any increase in total production will be based on synthetic ammonia. If sulfuric acid is readily available at a reasonable price, it is likely that the demand for ammonium sulfate could result in the production of some synthetic ammonium sulfate within the eight states.

5. Rayon and Cellulose Films and Fibers

In the production of regular rayon, cellulosic fibrous crumbs (xanthate) are wet-spun into a sulfuric acid bath, and the sulfuric acid converts the material to rayon. Approximately 1.5 pounds of H_2SO_4 are required for every pound of rayon produced, but part may be recovered in the form of sodium sulfate. In other similar processes, however, such as the production of cellulose acetate, only 0.15 pound is required. Cellophane (viscose cellulose) requires about 1.1 pounds of sulfuric acid per pound of product. We estimate that manufacturers in the selected marketing areas used approximately 360,000 tons of sulfuric acid in 1966 to produce these products. Table IV-12 lists the producers and estimated capacities of rayon and cellulosic films and fibers in the potential sulfuric acid producing areas.

TABLE IV-12

PRODUCERS AND ESTIMATED CAPACITIES OF RAYON AND CELLULOSIC FIBERS

Cellulosic Fibers	Product Type	Estimated Capacity (MM lbs)
FMC Corp.		
American Viscose		
Lewistown, Pa.	Viscose Rayon	80
Meadville, Pa.	Acetate	25
Nitro, W. Va.	Viscose Rayon	n.a.
Parkersburg, W. Va.	Viscose Rayon	n.a.
Eastman Kodak Co.		
Kingsport, Tenn.	Acetate	215
Beaunit Corp.		
Elizabethton, Tenn.	Cuprammonium Rayon	n.a.
	Viscose Rayon	150
American Enka Corp.		
Lowland, Tenn.	Viscose Rayon	90
Midland-Ross		
Painesville, Ohio	Viscose Rayon	90
Cellophane (Viscose Cellulose)		
E. I. du Pont de Nemours		
Clinton, Iowa		100
Olin Mathieson Corp.		
Olin (Covington), Ind.		33

Source: Stanford Research Institute

The outlook for increased production of rayon and other cellulosic products is not good. Substantial competition from synthetic fibers and films has been noted, and recent price decreases for the synthetics has exerted even further pressure on the cellulosics. In our sulfuric acid consumption projections, we indicate approximately level consumption of sulfuric acid for this purpose but recognize that it could decrease substantially, particularly if the cost of sulfuric acid continues to increase. Many of the plants producing rayon and other cellulosics are old and presumably depreciated. It would seem entirely possible that production could be discontinued at these plants in favor of the newer materials.

6. Titanium Dioxide

The only other significant use of sulfuric acid in the eight states is for the production of titanium dioxide. When titanium-bearing ore such as ilmenite or rutile is processed, sulfuric acid or chlorine may be used. In the sulfate process, approximately 4.55 tons of H_2SO_4 is required per ton of TiO_2 produced. Most of the titanium dioxide is utilized in paint manufacture, where the quality is measured in terms of "hiding power" of the paint. The sulfate process, however, has fallen from favor, since its product is slightly less desirable than that produced by the chlorination process. We believe, therefore, that there will be a strong trend toward increased use of the chlorination route to titanium dioxide, with corresponding decrease in the sulfate process.

There is only one producer of titanium dioxide within the areas we considered, National Lead Company in St. Louis, Missouri. This is a relatively large plant with production capacity estimated at 108,000 tons per year requiring approximately 490,000 tons of sulfuric acid if it operates at capacity. The plant operates on captive sulfuric acid, produced by the same company at the same location. Unless the company changes over to the chlorination process, we believe that it will continue to utilize sulfuric acid in the future at approximately the same rate as in the past. In either case, the potential market for a new supplier is virtually non-existent.

7. Other Uses

Sulfuric acid is used in a large number of other products, including explosives and many organic and inorganic chemicals. In the manufacture of explosives, sulfuric acid is used to dehydrate nitric acid; as produced, nitric acid does not normally exceed 60% concentration,and sulfuric acid is used to remove the moisture and upgrade the nitric to 99%. The residual or "spent" acid contains about 10% nitric and 73% sulfuric. In some cases, this acid is sent back to the sulfuric acid producer for reclaiming, but in others, it is sold to local users such as fertilizer producers who do not object to the presence of the nitric acid. Disposition of this spent acid is treated as a waste disposal problem, at prices sufficiently low to insure disposal. This can, and does, create substantial disruption of normal pricing patterns for sulfuric acid.

Among the many other uses for sulfuric acid are the production of dyes, insecticides, vegetable oils, and a number of other chemical and non-chemical products. Because of the larger variety of these, and the large number of small producers associated with these industries, we have not attempted to determine any exact quantities of sulfuric acid consumed.

D. SULFURIC ACID CONSUMPTION IN POTENTIAL PRODUCING AREAS

1. Pittsburgh Region (Table IV-13)

There are only two normal superphosphate (NSP) plants in the Pittsburgh region; these are located in the Cleveland, Ohio area and are captively supplied. Capacity to produce normal superphosphate is 150,000 tons, but utilization is estimated at only about 35%. There are no phosphoric acid plants located within 150 miles of Pittsburgh.

TABLE IV-13

MAJOR SULFURIC ACID CONSUMERS AND ESTIMATED DEMAND IN PITTSBURGH AREA, 1967

(within 150 miles of Pittsburgh)

		Product & Capacity[1] (000 tons per year)	Estimated Sulfuric Acid Demand, 1967 (000 tons per year)		Remarks
			Captive	Merchant	
Fertilizers					
Continental Oil	- Cleveland, Ohio	NSP - 100	14		
Swift & Co.	- Cleveland, Ohio	NSP - 50	4		
Various companies	- mixing plants	Mixed Fertilizers	3	7	Largely merchant
Ammonium Sulfate					
Bethlehem Steel	- Johnstown, Pa.	COBP- 22.0		24	
Crucible Steel	- Midland, Pa.	COBP- 6.0		5	
Jones & Laughlin	- Aliquippa, Pa.	COBP- 22.0		17	
	- Pittsburgh, Pa.	COBP- 25.0		18	
National Steel	- Weirton, W. Va.	COBP- 10.5		8	
Pittsburgh Steel	- Monessen, Pa.	COBP- 9.0		7	
Republic Steel	- Cleveland, Ohio	COBP- 30.2		23	
	- Masillon, Ohio	COBP- 1.5		1	
	- Warren, Ohio	COBP- 5.5		4	
	- Youngstown, Ohio	COBP- 15.4		12	Merchant
Sharon Steel	- Fairmount, W. Va.	COBP- 5.5		4	Merchant
Shenango, Inc.	- Pittsburgh, Pa.	COBP- 6.0		5	Former U.S. Steel - may be captive
U.S. Steel	- Clairton, Pa.	COBP- 110.0	83		
	- Fairless, Pa.	COBP- 13.3	10		
	- Lorain, Ohio	COBP- 22.0		17	
Wheeling Steel	- Follansbee, W. Va.	COBP- 20.0		15	
Youngstown Sheet & Tube	- Campbell, W.Va.	COBP- 110.0		83	

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1. Refinery capacity in barrels (42 gallons) alkylate per day

TABLE IV-13 (Continued)

		Product & Capacity (000 tons per year)	Estimated Sulfuric Acid Demand, 1967 (000 Tons per year)		Remarks
			Captive	Merchant	
Iron & Steel Pickling					
Bethlehem Steel	- Johnstown, Pa.	HS- ?		6	
Jones & Laughlin	- Cleveland, Ohio	HS - 1600		11	50% HCl 1967
	- Aliquippa, Pa.	HS - 1600		22	No HCl
	- Pittsburgh, Pa.	HS - 1500		21	No HCl
Pittsburgh Steel	- Allenport, Pa.	HS - 900		12	No HCl
Republic Steel	- Warren, Ohio	HS - 2100		--	May be 100% HCl
	- Cleveland, Ohio	HS - 2500		20	50% HCl
Sharon Steel	- Farrell, Pa.	HS - 900		3	75% HCl
U.S. Steel	- Fairless Hills, Pa.	HS - 3100	35		20% HCl
	- Dravosburg, Pa.	HS - 3100	19		No HCl
Wheeling Steel	- Steubenville, Ohio	HS - 1400		4	Near 100% HCl
Rayon and Cellulose Films and Fibers					
American Viscose (FMC)	- Lewistown, Pa.	VR - 40		283	
	- Meadville, Pa.	A - 40			
	- Nitro, W. Va.	VR) n.s. (large)			
	- Parkersburg, W. Va.	VR)			
Midland-Ross	- Painesville, Ohio	VR - 45			
Petroleum Refining					
United Refining	- Warren, Pa.	BAPD- 1100		3	
Witco Chemical	- Petrolia, Pa.	Lube Oil Additives		26	
Aluminum Sulfate					
Allied Chemical	- Chillicothe, Ohio) - Cleveland, Ohio)		25		
	- Johnsonburg, Pa.) - Newell, Pa.)		20		
Other Major Use					
Harshaw Chemical	- Cleveland, Ohio	HF, other chemicals	___	32	
		Total Major Uses	213	693	
			906		

A	Acetate
AmS	Ammonium sulfate
BAPD	Barrels alkylate product per day
COBP	Coke oven byproduct
DDBS	Dodecylbenzene sulfonate
HF	Hydrofluoric acid
HS	Hot strip
LAS	Linear alkyl sulfonate
NSP	Normal superphosphate
NP	Nitro-phosphate
PA	Phosphoric acid
VC	Viscose cellulose
VR	Viscose rayon

A number of steel companies have coke ovens in the Pittsburgh area, and a fairly large demand exists for sulfuric acid to produce ammonium sulfate. The largest demand is by U.S. Steel (Clairton and Fairless, Pa.), which gets acid from its own plant at Donora, Pa. The largest merchant demand exists from Youngstown Sheet and Tube in Campbell, West Virginia. We anticipate a declining demand for acid in this area, since its use is associated with coke oven byproduct ammonia (COBP) and coke demand is declining as steel mills shift over to the newer oxygen process.

In iron and steel pickling, we have attempted to show, where possible, the changes to hydrochloric acid. It should also be noted that the hot-strip(HS) capacity shown does not necessarily reflect the total demand; as pointed out earlier in the report, different quantities of sulfuric acid are utilized for different products. U. S. Steel is the only producer which has captive sulfuric acid production in the Pittsburgh area.

In cellulose films and fibers, viscose rayon (VR) currently accounts for the largest quantities of sulfuric acid.American Viscose (FMC) and Midland-Ross are the principal producers. However, we believe that the Painesville plant of Midland-Ross may be operating at reduced capacity, and our estimate may overstate the actual amount of acid consumed.

The only producer of aluminum sulfate in this area is Allied Chemical, which has plants in both Pennsylvania and Ohio. Its production is tied largely to captive sulfuric acid plants.

Harshaw Chemical at Cleveland, Ohio, produces hydrofluoric acid (HF) and various chemical sulfates. It is, however, on the fringe of the 150-mile circle from Pittsburgh and is probably supplied by acid from such areas as Detroit as well as from Cleveland itself.

The major uses for sulfuric acid account for 213,000 tons on a captive basis and 693,000 tons on a merchant basis, giving a total demand of 906,000 tons compared with a production capacity of 1.1 million tons.

There are some substantial buyers of acid in the Pittsburgh merchant market. Viscose rayon accounts for nearly one-third of total merchant sales, with annual individual plant requirements running as high as 75,000 tons H_2SO_4. For steel pickling (14% of merchant market), purchases can exceed 20,000 tons per year, and for ammonium sulfate (approximately 35% of merchant market in 1967), up to 83,000 tons of acid per year may be required. Further, because one company may have more than one manufacturing facility requiring acid in the area (e.g., FMC), total corporate purchases will be even higher.

Purchases of this magnitude fall in the second category of pricing schedules discussed earlier (long-term, large-volume contract) and therefore justify significant price discounts off list. We believe that as much as 50% of the available merchant market falls within this category. Precise price information is not available from either acid suppliers or users; we suspect however, that these large-volume purchases are made at prices in the neighborhood of \$18-\$22 per ton of acid.

Accordingly, a potential new supplier hoping to participate in the large-volume merchant market will be forced to at least meet current prices to obtain his share of this market. Since there are already three large merchant suppliers (Allied, DuPont, and St. Joseph Lead), one might reasonably estimate that a new supplier could expect to capture no more than one-fourth of the merchant market, or approximately 170,000 tons (500 TPD).

In order to assess this situation more fully, we derived Table IV-14 based strictly on locational factors and without regard to captive demand or trade relationships.

When the Pittsburgh region is further divided into smaller segments around supply points, a distinctly different pattern emerges. With this type of analysis, Pittsburgh and the immediately surrounding area (particularly to the west and north) becomes deficient in supply.

On this basis, it would appear that an opportunity might exist for a small pyrite-based plant, perhaps on the order of 500 tons per day.

Significantly, however, demand in the Pittsburgh region (and more particularly in the immediate area of Pittsburgh) is declining, as noted in Table IV-21. Declining demand will be principally in iron and steel pickling (reduction of 7000 tons H_2SO_4 by 1969 and likely to remain steady); and ammonium sulfate (reduction of 9000 tons H_2SO_4 by 1969 and further reduction of 15,000 tons H_2SO_4 by 1972). Demand for other uses will increase slightly, but not enough to offset these declines. Therefore, actual demand in the immediate Pittsburgh area will decline to about 485,000 tons H_2SO_4 by 1972.

TABLE IV-14

ANALYSIS OF SUPPLY-DEMAND IN PITTSBURGH AREA, 1967

(000 tons H_2SO_4)

	Total Demand	Closest Supply Point				
		Cleveland	Brownsville	Nitro	Pittsburgh	
Fertilizer	28	20	2	4	2	
Ammonium Sulfate	336	57	4	-	275	
Iron & Steel Pickling	153	31	-	-	122	
Rayon & Cellophane	283	25	25	150	83	
Petroleum	29	-	-	-	29	
Aluminum	45	25	20	-	-	
Other	32	32	-	-	-	
	906	190	51	154	511	
Producers (Capacity)	Total Capacity					
Allied Chemical	500	125	240	135	-	Largely merchant
Continental Oil	35	35	-	-	-	Captive
DuPont	200	200	-	-	-	Merchant
St. Joseph Lead	220	-	-	-	220	Merchant
U.S Steel	115	-	-	-	115	Captive
Witco Chemical	35	-	-	-	35	Captive
	1105	360	240	135	370	

In assessing these demand decreases, we foresee nothing that will act to prevent them, barring some new and unexpected development such as a new sulfuric-acid consuming industry. We are not aware of any plans for such a plant in this area. We also see nothing to prevent further erosion of the H_2SO_4 demand in iron and steel pickling and in ammonium sulfate. It seems fairly clear that pickling with HCl will become dominant in Pittsburgh, since several producers are already using it and the low price ($16 per ton for 32% HCl) is attractive, not to mention the waste pickle liquor disposal advantages. We believe the trend toward using less coke for steel manufacture is well established, and see nothing to prevent further declines in coke-oven operation. In fact, Jones & Laughlin, with an estimated 35,000 tons H_2SO_4 demand for ammonium sulfate in 1967, indicates that it is considering curtailment of coke-oven byproduct operations and in the future may recover crude tars only, for shipment to chemical companies for further processing.

In speculating about the effect of a pyrite-based sulfuric acid plant in Pittsburgh, it seems relevant to look at the following numbers (in thousands of tons H_2SO_4):

	1966	1972
Demand	511	485
Supply (capacity, 100% operation)	370	370
Balance	141	115
New plant - 500 TPD x 330 days/year		165
Surplus or displacement		50

These numbers clearly show that a 500-ton-per-day plant would provide a surplus of 50,000 tons H_2SO_4 if other plants were to operate at 100% of capacity. Similarly, a 1000-ton-per-day plant would give a surplus of 215,000 tons H_2SO_4. A 1500-ton-per-day plant could potentially absorb the entire market and still provide a 10,000-ton surplus. Thus, there appears to be little or no room for even a minimum sized (500 TPD) pyrite-based sulfuric acid plant.

2. Cairo, Illinois-Paducah, Kentucky Region (Table IV-15)

Demand by major end uses in the Cairo-Paducah area is estimated at about 190,000 tons H_2SO_4 in 1966. This is made up largely of normal superphosphate and mixed fertilizers and is also largely confined to Tennessee. Token amounts are consumed in ammonium sulfate production by Rohm & Haas at its byproduct plant near Louisville, Kentucky, in petroleum refining by Marathon Oil at Robinson, Illinois and by Pennsalt Chemical at Calvert City, Kentucky. Colgate-Palmolive consumes small amounts for detergent sulfonation at Jeffersonville, Indiana. However, many of these uses are far removed from Cairo-Paducah, particularly the Tennessee locations, which are well within shipping range of the large byproduct sulfuric acid plant of Tennessee Corporation at Copperhill, Tennessee.

TABLE IV-15

MAJOR SULFURIC ACID CONSUMERS AND ESTIMATED DEMAND IN CAIRO-PADUCAH AREA, 1967
(within 150 miles of Cairo)

		Product* Capacity (000 tons /year)	Sulfuric Acid Demand (000 tons 100% H_2SO_4)		Remarks
			Captive	Merchant	
Fertilizers					
Armour Agric. Chemical	- Nashville, Tenn.	NSP - 150	36		
Borden Chemical	- Russellville, Ky.	NSP - 50		4	May be closed down
Indiana Farm Bureau	- Jeffersonville, Ind.	NSP - 60		5	
Mobil Chemical	- Memphis, Tenn.	NSP - 50	13		
	- Mt. Pleasant, Tenn.	NSP - 25	6		Supplied from Memphis
W. R. Grace	- Nashville, Tenn.	NSP - 50		13	
Tennessee Farmers Coop.	- Lavergne, Tenn.	NSP - 30		7	
Texaco	- Nashville, Tenn.	NSP - 50		13	
Various producers	-	Mixed Fertilizers	7	3	Largely captive
Ammonium Sulfate					
Rohm & Haas	- Louisville, Ky.	AmS - 20		13	Acrylics by-product
Petroleum Refining					
Marathon Oil	- Robinson, Ill.	BAPD- 2600 Petro. additives		10	
Detergent Alkylate					
Colgate-Palmolive	- Jeffersonville, Ind.			15	
Other Major Use					
Pennsalt Chemical	- Calvert City, Ky.	HF - 18	45		
Total Major Uses			107	83	
			190		

*See Table IV-13 for explanation of abbreviations.

Even though demand exceeds supply (approximately 119,000 tons per year) in this region, the existing market is not attractive for a new producer. Users are small and scattered, and substantial sales effort would be required. All the acid producers in the area have captive demand for part of their output, but the Tennessee Corporation (Cities Service) plant in eastern Tennessee regularly ships acid into this area and absorbs part of the freight cost in order to be competitive. Its production is based on copper smelter gases, and the acid is believed to be low-cost. Estimated production in 1966 was 900,000 tons at full capacity; in 1967 capacity was increased to 950,000 tons. It seems doubtful that price reductions would gain a significant market share in this region.

An interesting possibility does exist for the Cairo-Paducah region. It is near the confluence of the Mississippi and Ohio rivers, and south of the confluence of the Mississippi and Missouri rivers. A large portion of the phosphate fertilizer is transported past the region by barge, either in the form of finished product or phosphate rock. Some interest has been expressed by the fertilizer industry in a sulfuric acid supply at Cairo-Paducah which could be used to convert phosphate rock into fertilizer for use farther up the river system. This possibility has been analyzed in detail in Section V.

3. St. Louis Region (Table IV- 16)

There are several phosphoric acid plants in the St. Louis area, utilizing phosphate rock which is barged in from Florida and sulfuric acid produced at the site. In addition, there are a number of normal superphosphate plants in the immediate location, none of which is operating at capacity. The largest consumer of sulfuric acid in the area is Sinclair Petrochemicals, which is completing a large ammonia and phosphoric acid and mixed fertilizer plant at Fort Madison, Iowa. Sinclair also is building a large brimstone-based sulfuric acid plant to supply its requirements.

A potential major user of sulfuric acid in this area is Chevron Chemicals, which has a large nitro-phosphate plant at Fort Madison, Iowa, in conjunction with an anhydrous ammonia plant. Largest demand, however, is for fertilizers containing water-soluble phosphates, and Chevron purchases phosphoric acid on a merchant basis. Chevron might be interested in producing its own, and if so, its sulfuric acid requirements could be as much as 120,000 tons per year.

There is only one steel company operating in the St. Louis area, Granite City Steel; it has a relatively small requirement for sulfuric acid for production of ammonium sulfate. The company pickles steel, but has gone largely to hydrochloric acid for this purpose.

Petroleum refining accounts for about 81,000 tons of H_2SO_4 in the St. Louis area and requirements are increasing. Both American Oil and Shell Oil utilize sulfuric acid to produce alkylate and also to produce other petroleum additives and chemicals. While this represents a fairly large merchant

TABLE IV-16

MAJOR SULFURIC ACID CONSUMERS AND ESTIMATED DEMAND IN ST. LOUIS AREA, 1967
(within 150 miles of St. Louis)

		Product* Capacity (000 tons/year)	Sulfuric Acid Demand		Remarks
			Captive	Merchant	
Fertilizers					
Allied Chemical	- E. St. Louis, Ill.	PA - 36 P_2O_5	95		
National Distillers	- Tuscola, Ill.	PA - 40 P_2O_5	105		
Sinclair Chemical	- Ft. Madison, Iowa	PA -200 P_2O_5	520		Under construction
Armour Agric. Chem.	- E. St. Louis, Ill.	NSP- 50		7	
FS Services	- E. St. Louis, Ill.	NSP- 50		9	
Mobil Chemical	- E. St. Louis, Ill.	NSP- 60		9	
Swift & Co.	- E. St. Louis, Ill.	NSP-100		14	Sulfuric acid plant not operating
Missouri Farmers Assn.	- Maryland Heights, Mo.	NSP- 50		15	
Chevron Chemical	- Ft. Madison, Iowa	NP -300 (45 P_2O_5)		(120)	Potential-see text
Various producers	-	Mixed Fertilizers	5	10	Largely merchant
Ammonium Sulfate					
Granite City Steel	- Granite City, Ill.	COBP- 6.0		5	
Iron & Steel Pickling					
Granite City Steel	- Granite City, Ill.	HS -1400		3	Nearly 100% HCl
Petroleum Refining					
American Oil	- Wood River, Ill.	BAPD-5300 Petro additives chemicals		20	
Shell Oil/Chemical	- Wood River, Ill.	BAPD-20,000 petrochemicals		55	
Texaco	- Lawrenceville, Ill.	BAPD-2500		6	

*See Table IV-13 for explanation of abbreviations.

TABLE IV- 16(Continued)

		Product Capacity	Sulfuric Acid Demand		Remarks
			Captive	Merchant	
Sulfonated Detergents					
Procter & Gamble	- St. Louis, Mo.			16	
Colgate-Palmolive	- St. Louis, Mo.			25	
Lever Bros.	- St. Louis, Mo.			16	
Aluminum Sulfate					
National Lead	- St. Louis, Mo		28		
Titanium Dioxide					
National Lead	- St. Louis, Mo.		410		
Total Major Uses			1163	210	
			1373		

market, it is competed for by local acid producers, who must have sludg burning facilities available.

All three of the major detergent producers have large sulfonation plants in St. Louis; we have estimated their total demand at the equivalent of approximately 57,000 annual tons H_2SO_4, but we recognize that some of this capacity may have been changed to sulfur trioxide sulfonation and may no longer be available to a sulfuric acid producer.

Other uses of sulfuric acid in the St. Louis area include production of aluminum sulfate and titanium dioxide by National Lead. Both of these are captively supplied by National Lead's own sulfuric acid plant and would not be available to a new producer.

The merchant market (0.2 million tons) in St. Louis is small in comparison with the captive demand of 1.2 million tons of sulfuric acid, and capacity (1.3 million tons, Table IV-19), including a plant now under construction, approximates this demand. Based on expected increases in phosphoric acid production in the area, sulfuric acid consumption may exceed 2 million tons by 1972. This offers an opportunity for a new producer, but a large plant (1500 tons per day) would almost certainly require captive uses in order to assure continuous operation in early years. None of the present captive consumers appear to need new acid supplies, and therefore a new producer would need to locate a new consuming plant in the region or else arrange to supply one or more existing consumers. The current sulfur shortage might make this possible over the next 5 years, but there is also the possibility of new sources of sulfuric acid becoming available, such as the new plant of St. Joseph Lead in Herculaneum, Missouri, based on smelter gases.

Because of its location with respect to existing and potential fertilizer markets, St. Louis is an attractive possibility for a large, new sulfuric acid plant associated with a phosphoric acid plant. From a marketing standpoint St. Louis is roughly similar to the Cairo-Paducah area, which is also close to fertilizer markets. However, Cairo-Paducah has a slight advantage in that it is closer to potential pyrite sources in the Illinois - Pennsylvania - Ohio region; hence, an acid plant in this area should have lower raw material costs.

Thus, while recognizing St. Louis' potential as a site for a pyrite-based operation, we have used Cairo-Paducah as our example in Section V when analyzing the economics of an integrated phosphate-fertilizer plant based on a pyrite feed.

4. Chicago Region (Table IV-17)

In the Chicago region, by far the largest amount of sulfuric acid is consumed in the production of phosphoric acid. Of the total demand of about 1.9 million tons, we estimate that over 1.2 million tons of sulfuric acid were used for this purpose in 1966. Total capacity is approximately 2.4 million tons.

The major producers are largely captive or have close ties with sulfuric acid producers. Des Plaines Chemicals, for example, does not have its own sulfuric acid plant but is owned jointly by Stauffer Chemical and Swift & Co., both of which have sulfuric acid plants in Chicago. Hooker Chemical (National Phosphate Division) currently purchases part of its requirements, but

TABLE IV-17

MAJOR SULFURIC ACID CONSUMERS AND ESTIMATED DEMAND IN CHICAGO AREA, 1967

(within 150 miles of Chicago)

		Product* & Capacity (000 tons)	Sulfuric Acid Demand (000 tons)		Remarks
			Captive	Merchant	
Fertilizers					
Des Plaines Chemical	- Morris, Ill.	PA - 50 P_2O_5	130		Joint Stauffer-Swift
Hooker Chemical	- Marseilles, Ill.	PA -100 P_2O_5	210	50	
New Jersey Zinc (Gulf & Western)	- Depue, Ill.	PA -150 P_2O_5	390		Acid from smelter gases
Olin Mathieson	- Joliet, Ill.	PA -140 P_2O_5	360		
Continental Oil	- Danville, Ill.	NSP - 50		7	Probably trades
	- Fulton, Ill.	NSP - 50	7		Probably trades
Armour Agric. Chem.	- Chicago Heights, Ill.	NSP -100	14		
Borden Chemical	- Indianapolis, Ind.	NSP - 50		6	Supplied by Marion Mfg.
	- Streator, Ill.	PA - 33 P_2O_5	35	50	Supplied by M-H Zinc
	- Streator, Ill.	NSP - 50		2	May be closed down
Gilchrist Plant Foods	- Morris, Ill.	NSP - 20		4	Uses Spent Acid
Indiana Farm Bureau	- Indianapolis, Ind.	NSP - 90		11	
	- Schererville, Ind.	NSP - 50		8	
International Minerals & Chemicals	- Indianapolis, Ind.	NSP - 50		6	Supplied by Marion Mfg.
	- Chicago Heights, Ill.	NSP - 60		9	Probably trades
Mobil Chemical	- Ft. Wayne, Ind.	NSP - 50		7	Probably trades
	- Dubuque, Iowa	NSP - 50		14	
Occidental Petroleum	- Ashkum, Ill.	NSP - 25		4	
F. S. Royster Guano	- Indianapolis, Ind.	NSP - 90		11	
	- Madison, Wisc.	NSP - 50		9	
Swift & Co.	- Calumet City, Ill.	NSP -100	14		Old chamber plant
Texaco	- Danville, Ill.	NSP - 50		7	
Various producers	-	Mixed Fertilizers	5	5	

TABLE IV-17 (Continued)

		Product*& Capacity	Sulfuric Acid Demand		Remarks
			Captive	Merchant	
Ammonium Sulfate					
Citizen Coke & Gas	- Indianapolis, Ind.	COBP- 5.5		4	
Inland Steel	- Indiana Harbor, Ind.	COBP- 40.0		30	
Interlake Steel	- So. Chicago, Ill.	COBP- 6.0		5	
International Harvester	So. Chicago, Ill.	COBP- 12.0		9	
Republic Steel	- Chicago, Ill.	COBP- 5.5		4	
U.S. Steel	- Gary, Ind.	COBP- 75.0		56	May close down
	- Joliet, Ill.	COBP- 7.0		5	
Iron & Bteel Pickling					
Acme Steel	- Chicago, Ill.	HS -800		6	No HCl
Inland Steel	- E. Chicago, Ind.	HS -3700		26	50% to HCl
U.S. Steel	- Gary, Ind.	HS -3300		35	Now 25% to HCl 100% to HCl by 1969
	- Chicago, Ill.	HS -(700)		5	May be closed down
	- Joliet, Ill.	HS, wire - ?		12	
Youngstown Sheet & Tube	E. Chicago,Ill.	HS -2000		28	No HCl
Republic Steel	- So. Chicago, Ill.	Bar, wire - 1635		15	
Keystone Steel & Wire	- Peoria, Ill.	Wire - 520		11	
Northwestern Steel & Wire	- Sterling, Ill.	Bar, wire - 1150		15	
Bethlehem Steel	- Burns Harbor, Ind.	HS-?		16	
Rayon & Cellulose Films & Fibers					
E. I. du Pont de Nemours	-Clinton, Iowa	VC - 50		55	
Olin Mathieson	- Olin (Covington), Ind.	VC - 17		19	

TABLE IV-17 (Continued)

		Product*& Capacity	Sulfuric Acid Demand		Remarks
			Captive	Merchant	
Petroleum Refineries					
Texaco	- Lockport, Ill.	BAPD-4400		11	
American Oil	- Whiting, Ind.	BAPD-15500) Petroleum additives)	38		Trades sulfur for acid
Cities Service	- E. Chicago, Ind.	BAPD-4200		10	
Mobil Oil	- E. Chicago, Ind.	BAPD-3000		7	
Sinclair	- E. Chicago, Ind.	BAPD-5000		12	
Detergent Alkylation					
Procter & Gamble	- Chicago, Ill.	DDBS- 12		16	May change to SO_3 in 2 - 3 years
Witco Chemical	- Kilbourn, Ill.) - Chicago, Ill.)	DDBS- 5		6	
Continental Oil	- Chicago, Ill.) - Hammond, Ind.)	DDBS- 10 LAS - ?		6	
Stepan Chemical	- Millsdale, Ill.	DDBS- 10		--	Uses SO_3 method
Richardson Co.	- Chicago, Ill	DDBS- 12		nil	Uses SO_3 method
Others	- Mostly Ill.			5	
Aluminum Sulfate					
American Cyanamid	- Joliet, Ill.		12		
Other Major Use					
Olin Mathieson	- Joliet, Ill.	HF, other chemicals	38		
	Total Major Uses		1253	639	
			1,892		

*See Table IV-13 for explanation of abbreviations.

would add to its sulfuric acid plant if sulfur were readily available. New Jersey Zinc (Gulf & Western Industries) has recently completed a large sulfuric acid plant in Depue, Illinois, based on smelter gases from the roasting of zinc ores, and is producing phosphoric acid for further conversion to di-ammonium phosphate. Olin-**Mathieson** (Blockson Chemical Division) has a very large phosphoric acid plant at Joliet, Ill., to supply its captive and merchant requirements.

Other fertilizer producers in the area include Continental Oil, which has a captive supply of sulfuric acid at Fulton, Illinois, and probably trades for its requirements at Danville, Illinois. Borden Chemical at Streator, Illinois, produces part of its own requirement but buys even more from Matthiessen-Hegeler Zinc Co. at nearby La Salle. Borden is closing down its normal superphosphate plant at Streator. In Indianapolis, Borden and International Minerals and Chemical receive their sulfuric acid supplies from Marion Manufacturing Co.; we believe that these two users account for the largest part of Marion's output. Indiana Farm Bureau still produces token quantities of normal superphosphate, but it is turning more to phosphoric acid as a source of P_2O_5 in its mixed fertilizers.

Among the other fertilizer producers, Texaco (Federal Chemical Division) has ties with National Distillers' sulfuric acid plant at Danville; Federal Chemical was formerly part of the National Distillers group.

Large quantities of ammonium sulfate are produced in the Chicago area, all as byproduct of coke oven operations. However, the largest producer, U.S. Steel at Gary, Indiana, may be curtailing its operation due to reduced demand for coke in its steel-making plants.

Several of the steel producers in the Chicago area have indicated their plans to continue the trend toward hydrochloric acid steel pickling. U. S. Steel at Gary, Indiana, for example, now uses about 25% HCl in its pickling operating and will go to 100% by 1969. Inland Steel at East Chicago, Indiana, is now at 50% HCl. At Burus Harbor, Bethlehem Steel currently uses some 16,000 tons per year of sulfuric acid for one hot strip line. By the end of 1968, however, the company expects to switch to hydrochloric acid pickling for both the existing line and a new line as well. Acme Steel and Youngstown Sheet & Tube do not use any HCl and do not have plans to do so.

Rayon and cellulose films and fiber production in the Chicago area has not increased appreciably in recent years. The DuPont plant at Clinton, Iowa, for example, formerly relied on sulfuric acid from Continental Oil's plant across the river at Fulton, Illinois, but now receives supplies from its affiliated plant in East Chicago, Indiana. The increased acid cost, and the relatively static market for cellophane, prevents further increases in demand.

Among petroleum refineries in the Chicago area, American Oil at Whiting, Indiana, recovers at least 75 tons of sulfur per day in its refinery operation and sells this to Stauffer Chemical,which supplies it with sulfuric acid. Basically, American Oil is a net supplier of sulfur to Stauffer. An affiliated company of American Oil, Tuloma Gas, has a large demand for phosphate fertilizers in the Midwest and elsewhere, and American Oil presumably could decide to produce its own sulfuric acid for conversion into fertilizers.

Several of the sulfonated detergent producers in the Chicago area have already changed over to sulfur trioxide, and others (including Procter & Gamble) may do so within the next two or three years. There are, however, a number of small producers, mostly in Illinois, which are not likely to change over due to the investment needed in a sulfur trioxide sulfonating plant.

Other major sulfuric acid consumers in the area include American Cyanamid, which produces aluminum sulfate at Joliet, Illinois, and Olin-Mathieson, which produces hydrofluoric acid and other sulfated chemicals at Joliet. Both of these, however, have sulfuric acid plants at these locations and would not be available to a merchant supplier.

In summary, the Chicago area, with a capacity of 2.4 million tons, captive demand of 1.3 million tons and merchant demand of 0.7 million tons, has the potential to supply an additional 400,000 tons of acid to meet new or expanding demand. With the present sulfur shortage, a new supplier of acid might be able to obtain a reasonable share of the market. By 1972, we project acid demand in the Chicago area to reach approximately 2.6 million tons. Thus, by that time, new or additional production capacity may be needed. A large, new acid supplier should be associated with a captive consumer. Projected increases in demand indicate that phosphoric acid production will increase most rapidly, and this demand is largely captive.

However, Chicago is a considerable distance from pyrite source areas as defined in this study, and the additional freight cost ($1.60 per ton) associated with transportation of pyrite from Cairo-Paducah to Chicago would increase raw material costs significantly. Pyrite from along the Ohio River would probably also have to compete with Canadian brimstone shipped into Chicago at prices competitive with Gulf Coast delivered prices.

5. Sulfuric Acid Demand Summary

In Table IV-18 we have summarized the major end uses of sulfuric acid in each of the potential producing areas. As this table shows, Chicago is the largest consuming area, accounting for about 44% of the estimated total consumption. St. Louis accounts for about 32% and Pittsburgh for about 21%. The production of phosphoric acid accounts for about 45% of the total; ammonium sulfate accounts for 11%, while none of the other listed uses account for as much as 10%.

6. Sulfuric Acid Supply

The sulfuric acid producers and their estimated capacities in each of the areas under consideration are shown in Table IV-19. The largest of these

TABLE IV-18

SUMMARY OF ESTIMATED SULFURIC ACID DEMAND IN POTENTIAL PRODUCING AREAS, 1966
(thousands of short tons 100% H_2SO_4)

	Pittsburgh	Cairo-Paducah	St. Louis	Chicago	Total
Fertilizers					
Phosphoric Acid	--	--	720	1225	1945
Normal Superphosphate	18	97	54	140	309
Other Fertilizers	10	10	15	10	45
Ammonium Sulfate	336	13	5	113	467
Iron & Steel Pickling	153	--	3	169	325
Rayon and Cellulose Films & Fibers	283	--	--	74	357
Petroleum Refineries	29	10	81	78	198
Sulfonated Detergents	--	15	57	33	105
Aluminum Sulfate	45	--	28	12	85
Titanium Dioxide	--	--	410	--	410
Hydrofluoric Acid	32	45	--	38	115
Total Major End-Uses	906	190	1373	1892	4361
Captive	213	107	1163	1253	2736
Merchant	693	83	210	639	1625

TABLE IV-19

SULFURIC ACID PRODUCERS AND ESTIMATED CAPACITIES IN COMPETITIVE AREAS
(within 150 miles of area centers)

Company Name	Plant Location	Raw Material(s)	Estimated Capacity 1/1/68 (000 tons H_2SO_4)
Pittsburgh Area			
Allied Chemical Corp.	Cleveland, Ohio Newell (Brownsville), Pa. Nitro, W. Va.	Sulfur Sulfur, sludge, pyrites Sulfur	125 240 135
Continental Oil Co.	Cleveland, Ohio	Sulfur	35
E. I. du Pont de Nemours Co.	Cleveland, Ohio	Sulfur	200
St. Joseph Lead Co.	Josephtown, (Monaca) Pa.	Smelter gases	220
U.S. Steel Corp.	Donora, Pa. Pittsburgh, Pa.	Sulfur Sulfur	115 n.a. may not be operating
Witco Chemical Co., Inc.	Petrolia, Pa.	Sulfur, sludge	35
	Subtotal		1105
Cairo-Paducah Area			
Armour Agricultural Chemical Co.	Nashville, Tenn.	Sulfur	56
Mobil Chemical Corp.	Memphis, Tenn.	Sulfur	18
Pennsalt Chemical Corp.	Calvert City, Ky.	Sulfur	45
	Subtotal		119

TABLE IV-19 (Continued)

Company Name	Plant Location	Raw Material(s)	Estimated Capacity 1/1/68 (000 tons H_2SO_4)
St. Louis Area			
Allied Chemical Corp.	E. St. Louis, Ill.	Sulfur, sludge	180
American Zinc, Lead & Smelting Co.	Fairmont City, Ill.	Sulfur, smelter gases	116
Continental Oil Co.	E. St. Louis, Ill.	Sulfur	(25) may not be operating
Monsanto Co.	Monsanto, Ill.	Sulfur	280
National Distillers & Chem. Corp.	Tuscola, Ill.	Sulfur	140
National Lead Co.	Carondelet, Mo.	Sulfur	525
Chas. Pfizer & Co., Inc.	E. St. Louis, Ill.	Sulfur	6
St. Joseph Lead	Herculaneum, Mo.	Smelter gases	100 Under construction
Subtotal			1347
Chicago Area			
Allied Chemical Corp.	Hegewisch, Ill.	Sulfur, sludge	130
American Cyanamid Co.	Joliet, Ill.	Sulfur	60
Armour Agricultural Chemical	Chicago Heights, Ill.	Sulfur	35
Borden Chemical Co.	Streator, Ill.	Sulfur	35
Continental Oil Co.	Fulton, Ill.	Sulfur	16
E. I. du Pont de Nemours & Co.	E. Chicago, Ind.	Sulfur, sludge, smelter gases	325
Hooker Chemical Corp.	Marseilles, Ill.	Sulfur	210

TABLE IV- 19(Continued)

Company Name	Plant Location	Raw Material(s)	Estimated Capacity 1/1/68 (000 tons H_2SO_4)
Chicago Area (cont'd)			
Marion Manufacturing Co.	Indianapolis, Ind.	Sulfur	60
Matthiessen & Hegeler Zinc. Co.	LaSalle, Ill.	Sulfur, smelter gases	39
New Jersey Zinc Co.	Depue, Ill.	Smelter gases	420
Minnesota Mining & Mfg. Co.	Copley, Ohio	Sulfur	70
National Distillers & Chemical Co.	Dubuque, Io.	Sulfur	73
Olin Mathieson Chemical Corp.	Joliet, Ill.	Sulfur	350
F. S. Royster Guano Co.	Madison, Wisc.	Sulfur	36
Stauffer Chemical Co.	Hammond, Ind.	Sulfur, sludge	275
Swift & Co.	Calumet City, Ill.	Sulfur	40
Wilson & Co.	Elwood, Ill.	Sulfur	200 Ships Spent Acid
	Subtotal		2374
		Total	4945

is Allied Chemical, which has 850,000 tons capacity or about 17% of the total. Du Pont has 525,000 tons, as does National Lead Company. Du Pont, however, may have curtailed production at its East Chicago, Indiana, plant; with the opening of the Depue facility, it has ceased to be the roaster for New Jersey Zinc.

A number of the sulfuric acid plants in this area are of the old lead chamber type and may not be operating at capacity. However, most of the newer contact-type plants can operate at rates up to 25% in excess of rated capacity. Sulfur supplies in the area, however, have been short since early 1967, when sulfur companies began allocating sulfur on the basis of former shipments. At the present time, we understand that allocations are about 65% of normal, and sulfuric acid producers are required to utilize the sulfur at specific points. In other words, an acid producer cannot accumulate quotas from several plants to supply one large plant and keep it operating at or above rated capacity. Therefore, we believe that many of the small chamber plants are still operating in order to make the most efficient use of the sulfur allocations. With increased supplies of sulfur, however, most of these plants would likely be closed down.

Total capacity in the area amounts to nearly 5 million tons of H_2SO_4, of which nearly 50% is located in the Chicago area. St. Louis accounts for about 27% and Pittsburgh for 22%. Only a small amount of capacity is located in the Cairo-Paducah area, but as noted elsewhere, this market area is supplied by the large plant of Tennessee Corporation at Copperhill, Tennessee, which is able to ship longer distances than most sulfuric acid plants because of its low-cost byproduct output.

7. Estimated Supply-Demand in Potential Producing Areas

In Table IV-20 we have summarized the estimated demand for the major sulfuric acid uses for the years 1966, 1969 and 1972. The expected growth of phosphoric acid is clearly the most important factor in the region; phosphoric acid will account for 58% of the total in 1972 compared with about 45% in 1966.

It will be noted that projected demand for sulfuric acid by phosphoric acid producers approximates a growth rate of 9% per year, substantially higher than the expected national growth rate of 4-5% per year. This higher rate is based on phosphate fertilizer demand growing more rapidly in this section of the country than the national demand, as noted in Chapter V, Table V-1. In addition, we have also assumed that some credit must be given to the desire of fertilizer marketers, who now purchase their phosphate fertilizers, to initiate production in this section of the country close to their markets. Obviously, our projections are subject to several conditions, including whether it is less expensive to produce phosphate fertilizers in the Midwest as compared to similar production in Florida and transport of the finished product to the Midwest. These factors and conditions are examined in detail in Chapter V, but on balance we believe that Midwest phosphate fertilizer-production does present favorable economics. We feel, therefore, that we are justified in projecting a growth rate for sulfuric acid to be used in phosphoric acid manufacture in the Midwest higher than the national rate.

TABLE IV-20

PROJECTED SULFURIC ACID CONSUMPTION BY MAJOR END USE IN POTENTIAL PRODUCING AREAS
(within 150 mile radius of: Pittsburgh, Cairo-Paducah, St. Louis, Chicago)

	1966	1969	1972
Fertilizers:			
Phosphoric Acid	1945	2550	3300
Normal Superphosphate	309	310	300
Other Fertilizers	45	35	25
Ammonium Sulfate	467	495	520
Iron & Steel Pickling	325	290	235
Rayon & Cellulose Films & Fibers	357	350	350
Petroleum Refineries	198	220	245
Sulfonated Detergents	105	110	115
Aluminum Sulfate	85	95	105
Titanium Dioxide	410	410	410
Hydrofluoric Acid	115	130	145
Total Major End Uses	4361	4995	5750

The purpose of Table IV-21 is primarily to show opportunities for the erection of a sulfuric acid plant in each of these regions. We have assumed that where the estimated demand is less than capacity, then only a minimal opportunity would be available, since a new producer would be forced to compete with those that are well established. On the other hand, in an area where demand exceeds the supply, then additional sulfuric acid is shipped in from outside the area, and these shipments would be vulnerable to a new producer.

The Table shows that both St. Louis and Chicago are expected to require additional supplies of sulfuric acid by 1972, with St. Louis having the greatest need. Acid demand in Pittsburgh is expected to decline from current levels, while normal requirements in the Cairo-Paducah area should remain about the same.

As previously mentioned, however, Cairo-Paducah is located nearer the pyrite source areas and at the same time is well within reach of the large midwestern fertilizer market. Thus, assuming the desirability of an integrated operation, we believe the Cairo-Paducah area is the preferred location for a new pyrite-based acid plant. Conceivably, the new plant could also participate in the St. Louis merchant market.

Opportunities for a new plant to supply only the merchant market do not appear attractive. Overall, merchant demand amounted to 1.6 million tons of sulfuric acid in 1966, about 37% of the total. Merchant demand is composed largely of such uses as steel pickling (for which sulfuric acid demand

TABLE IV-21

SULFURIC ACID SUPPLY AND ESTIMATED DEMAND IN POTENTIAL PRODUCING AREAS
(thousands of tons H_2SO_4)

	Estimated Capacity 1/1/68	Estimated Demand (major uses only)		
		1966	1969	1972
Pittsburgh area	1105	906	875	840
Cairo-Paducah area	119	190	190	195
St. Louis area	1347	1373	1720	2095
Chicago area	2374	1892	2210	2620
Total	4945	4360	4995	5750

demand will decline), rayon and cellophane (which is expected to remain at current levels of acid use), and ammonium sulfate and petroleum refining (which will increase only moderately). It seems clear, therefore, that a new, large-scale producer would be required to produce for captive consumption, either by itself or by virtue of a joint venture with a partner interested in marketing the end product. Fertilizers based on phosphoric acid appear to offer the most interesting possibilities.

The current(1968) sulfur allocations have caused some confusion relative to the supply situation and, thus, the supply-demand balance in future years. However, we note that the real shortage is in sulfur at domestic prices ($41 per long ton in March, 1968); apparently adequate quantities of imported sulfur are available, at higher prices, to enable acid producers to operate at full capacity, providing markets for the higher-priced acid can be found. The recent increases in list prices for acid indicate this may, in fact, be happening, since the increases have generally been higher than domestic sulfur price increases would seem to warrant. We note also that substantial effort has been devoted to increasing the supply of sulfur, probably stimulated by the higher sulfur prices. Some new projects are already in operation, and others are scheduled over the next several years. On balance, we feel that sulfur supply will not be a limiting factor in the future.

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V. INTEGRATION OF ALL FACTORS IN PRICE VALUATION OF PYRITES FOR SUPPLYING SULFURIC ACID AND STEAM TO A LARGE PHOSPHATE FERTILIZER PROJECT

A. PROCESS DESCRIPTION FOR PHOSPHATE FERTILIZER MANUFACTURING

Phosphate -- which in nature occurs in chemical and physical combination with other substances -- is one of the three primary plant nutrients required by all forms of vegetation. The phosphate content of the phosphate-containing mineral is usually measured in terms of the phosphorus pentoxide (P_2O_5) equivalent. Commercial-grade phosphate rock deposits in the United States normally produce phosphate rock containing between 28 and 34% P_2O_5.

Since phosphate rock is quite insoluble and therefore unavailable to vegetation in its natural form, it must be treated chemically to produce soluble phosphates for fertilizer use. By far the most commonly used chemical for solubilizing phosphate rock is sulfuric acid. At present, 90-95% of all phosphatic fertilizers is produced via the sulfuric acid route. Quantities of acid used vary depending on the type of phosphate fertilizer to be produced; a ton of P_2O_5 derived as phosphoric acid requires about 2.6 tons of H_2SO_4, while the same quantity derived as normal superphosphate requires about 1.8 tons of H_2SO_4.

As is true in other parts of the chemical industry, phosphate fertilizer manufacturing plants have steadily become larger. New phosphate fertilizer projects are being designed with an annual P_2O_5 capacity of 200,000 tons, equivalent to 600 tons per day of P_2O_5. A 200,000-ton-per-year P_2O_5 plant will require a sulfuric acid capacity of about 540,000 tons per year, or 1,500-1,600 tons per day of 100% H_2SO_4. In the discussion which follows, we have assumed a phosphate fertilizer plant will have this sulfuric acid capacity.

B. REGIONAL PHOSPHATE DEMAND-SUPPLY OUTLOOK IN THE UNITED STATES

1. Demand

Since phosphatic fertilizer is a bulk commodity that sells at a low price, transportation costs for both the fertilizer itself and for the raw materials required in its manufacture become very important in determining project economics. The sulfur content of pyrite is about half that of brimstone (elemental sulfur) -- the predominant source of sulfur for producing phosphatic fertilizers at the present time. Thus, a pyrite-phosphate complex must be carefully situated so that the inbound transport cost for pyrite and phosphate rock and the outbound transport cost for the finished phosphate fertilizer be minimized. For this reason, it is important to review the regional supply-demand situation for phosphatic fertilizers in the United States to first determine where the most promising growth areas for phosphates will be.

Table V-1 presents phosphatic fertilizer consumption by region for 1965-66 along with projections for 1970-71 and 1975-76 into the future. In the fertilizer year ending June 30, 1966, U.S. phosphate fertilizer consumption totaled about 3.9 million short tons of P_2O_5.

Over the next ten-year period, we estimate that phosphatic fertilizer demand in the United States will increase to about 7.4 million short tons of P_2O_5,

TABLE V-1

U. S. PHOSPHATE FERTILIZER CONSUMPTION

(thousands of short tons P_2O_5)

Region*	1965/66	1970/71	1975/76
New England	52	59	64
Middle Atlantic	256	305	346
South Atlantic	512	670	830
East North Central**	1,168	1,638	2,145
West North Central	939	1,405	1,970
East South Central***	241	322	425
West South Central	347	545	800
Mountain	163	260	395
Pacific	195	196	435
Total	3,873	5,400	7,400

*Regions are shown in Figure V-1

**Plus Kentucky

***Less Kentucky

Sources: 1965/66 - U. S. Department of Agriculture
1970/71 & 1975/76 - Arthur D. Little, Inc.

representing an annual increase of about 6.5% per year. This growth rate is slightly better than the recent P_2O_5 growth rate in the U.S.

As Table V-1 shows, the largest phosphate-consuming areas in the United States are now located in the upper Midwest. Since the Midwest farming area of the United States will continue to at least maintain its share of the national phosphate fertilizer market, this region will continue to be the most important fertilizer-consuming area in the United States.

2. Demand-Supply

Figure V-1 presents the demand-supply balance for phosphatic fertilizers in the United States by region for 1971. The upper figure in each region represents the projected phosphate demand. The middle figure represents estimated phosphate fertilizer production capacity based upon present and recently announced new projects; and the bottom figure represents the surplus (or deficit) in phosphate capacity in each region. Figure V-1 also contains a summary of the demand-supply balance for phosphate for the United States as a whole.

While projected phosphate fertilizer demand for the United States will be about 5.4 million tons of P_2O_5 in 1971, present and on-coming phosphate capacity will be about 8.6 million tons of P_2O_5, representing a surplus capacity of about 3.2 million tons. This surplus will not be distributed evenly throughout

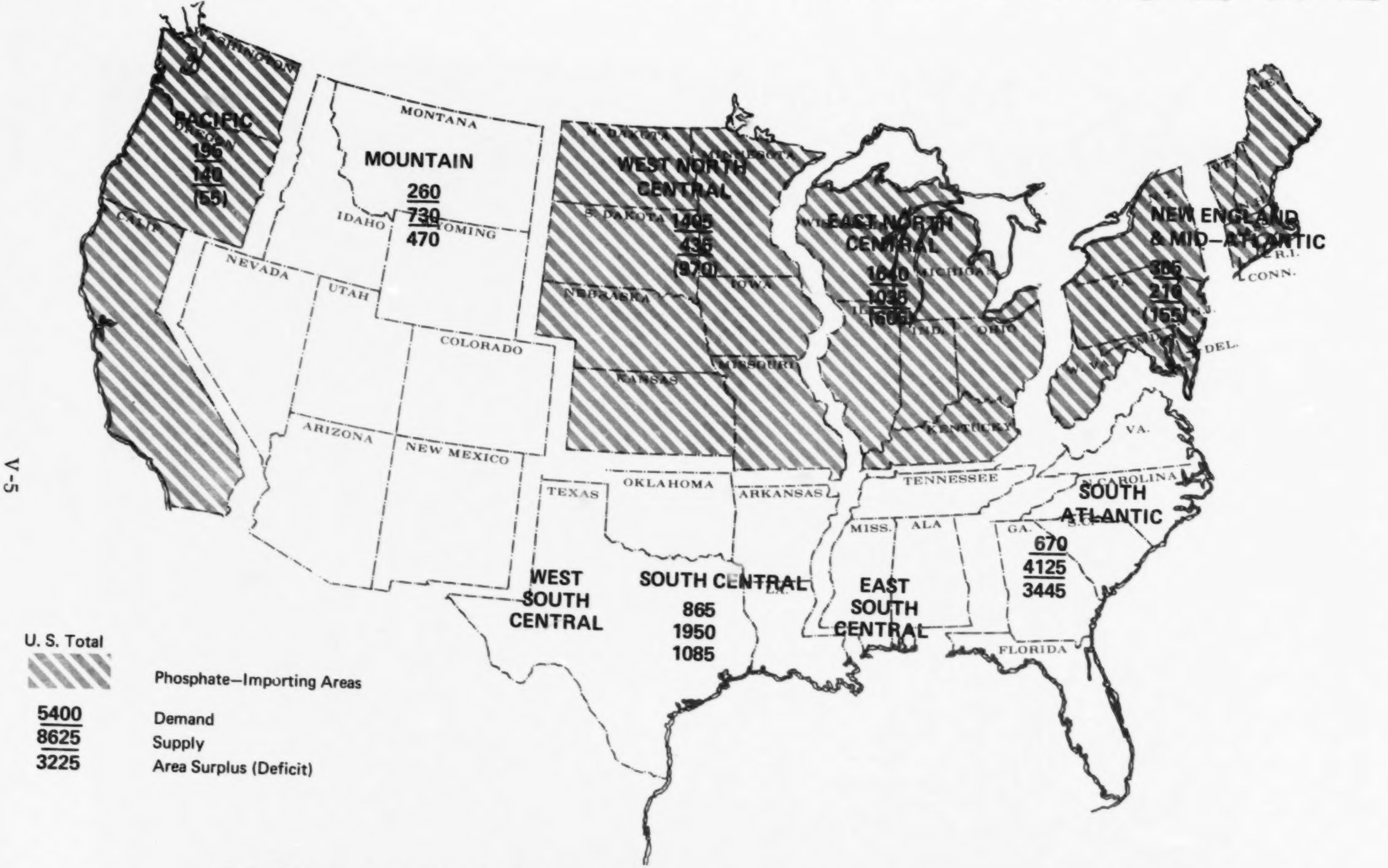

FIGURE V-1 REGIONAL-SUPPLY-DEMAND BALANCE FOR PHOSPHATE FERTILIZERS 1970-1971

(000's of Short Tons P_2O_5)

the United States. Thus, some regions (the unshaded areas in Figure V-1) will have a surplus capacity and will be net exporters of phosphates, but others (the shaded areas) will be net importers. In brief, the upper Midwest (West North Central and East North Central) regions will be the largest phosphate importers, and the South Atlantic and South Central regions will be the principal areas from which these phosphates will be supplied.

Since the sulfur requirements for phosphate manufacture are the prime focus of this study, Figure V-2 shows the sulfur equivalent that will be required for the phosphate volumes presented in Figure V-1. (The differences in sulfur-to-P_2O_5 ratios from region to region reflect the differences in the amount of P_2O_5 obtained from normal superphosphate versus that from phosphoric acid; the sulfur equivalents are 0.6 and 0.87, respectively. The total U.S. phosphate demand of 5.4 million tons for 1971 (see Figure V-1) is equivalent to a requirement of 4.2 million short tons of sulfur. Expressed in another way, it takes, on the average, about 0.78 short ton of sulfur for each short ton of available P_2O_5. On this basis, the phosphate fertilizer import requirements of the West North Central and East North Central regions in 1971 will be equivalent to about 725,000 tons and 455,000 tons of sulfur, respectively. Conversely, the South Central and South Atlantic regions will need to export 905,000 tons and 2,930,000 tons of sulfur equivalent, respectively, if they are to operate their facilities at rated capacity. Since a surplus of phosphate production capacity is visualized for 1971, it is clear that these Southern-based plants will not operate at designed capacity unless they can export large tonnages of phosphatic fertilizers overseas.

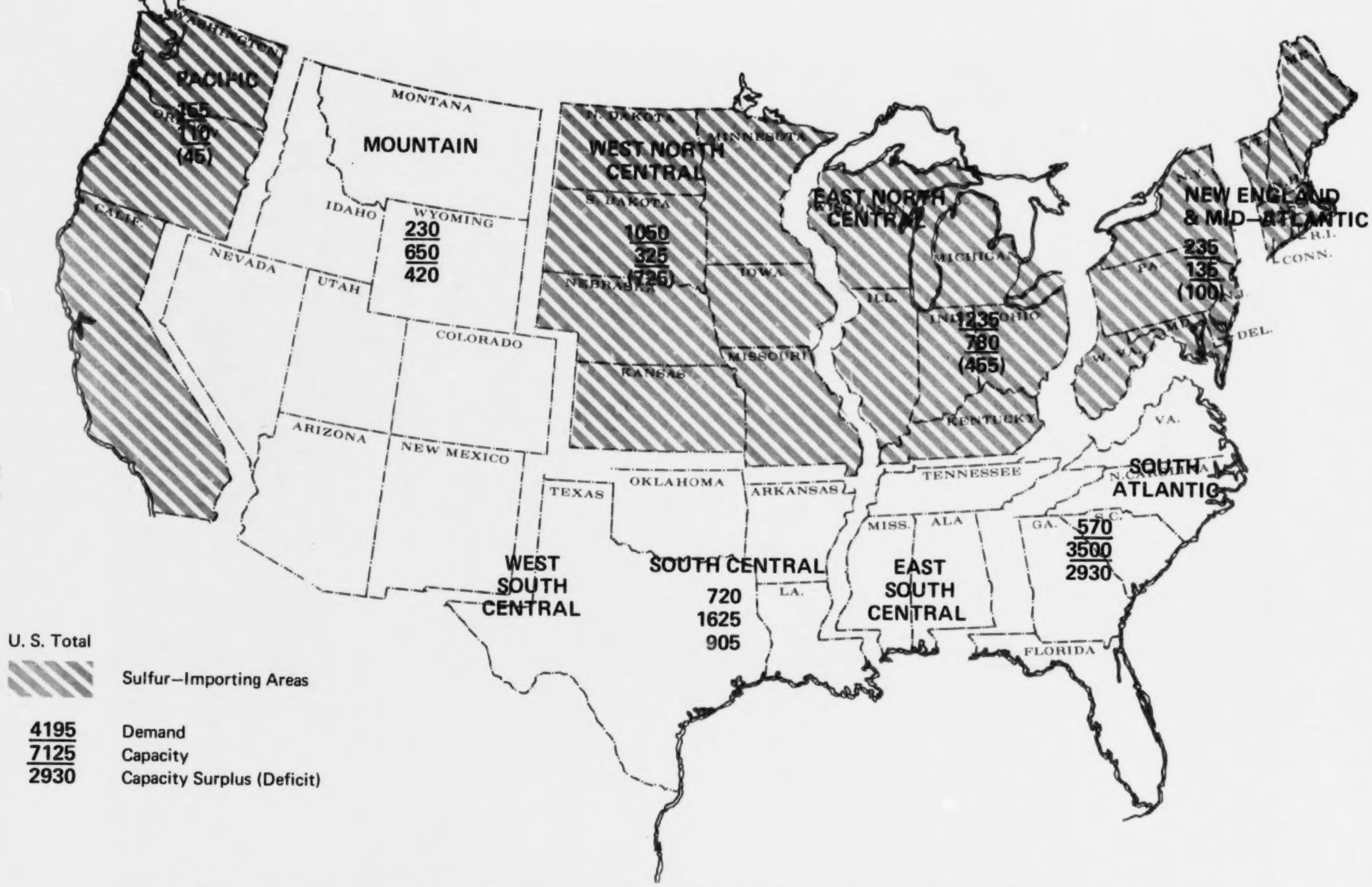

FIGURE V-2 REGIONAL COMPARISON OF SULFUR REQUIREMENTS FOR PHOSPHATIC FERTILIZER DEMAND VERSUS SULFUR CONSUMED WITHIN EACH REGION FOR PHOSPHATE MANUFACTURING, 1970-1971

(000's of Short Tons of Sulfur)

C. PHOSPHATE-TRADE ROUTE PATTERNS TO SERVE UPPER MIDWEST MARKETS

From the foregoing discussion, it is reasonable to assume most of the phosphates which the upper Midwest area will require in 1971 will come from plants lying to the South. Figure V-3 shows the concentration of surplus phosphate production both in the United States and in Western Canada and how we visualize these surplus phosphates will move to reach the Midwest and other deficit areas. Two figures attached to each arrow denote phosphate flow. The top figure denotes the thousands of tons of P_2O_5 in the movement and the bottom figure the equivalent amount of sulfur required to produce this quantity of phosphate. As Figure V-3 shows, by far the largest movement of phosphate into the Midwest will originate from Gulf Coast phosphate plants located in Florida and the Louisiana-Texas area. Lesser quantities will come from plants located in Southern Canada and in the Idaho-Utah area.

D. PLANT LOCATION CONSIDERATIONS FOR A PHOSPHATE PLANT BASED UPON SULFURIC ACID FROM PYRITES

It was pointed out earlier that the plant location for a phosphate project is determined to a large extent by the transportation cost for both incoming and outgoing materials. Today, most of the modern phosphate fertilizer plants are located in Florida, where phosphate rock is produced. Elemental sulfur is shipped from the central Gulf Coast area into Tampa and thence transported to the phosphate rock conversion plant. The outbound phosphatic fertilizers move either directly by rail to the Midwest market or back through the port of Tampa onto barges which move across the Gulf and then northward up the Mississippi

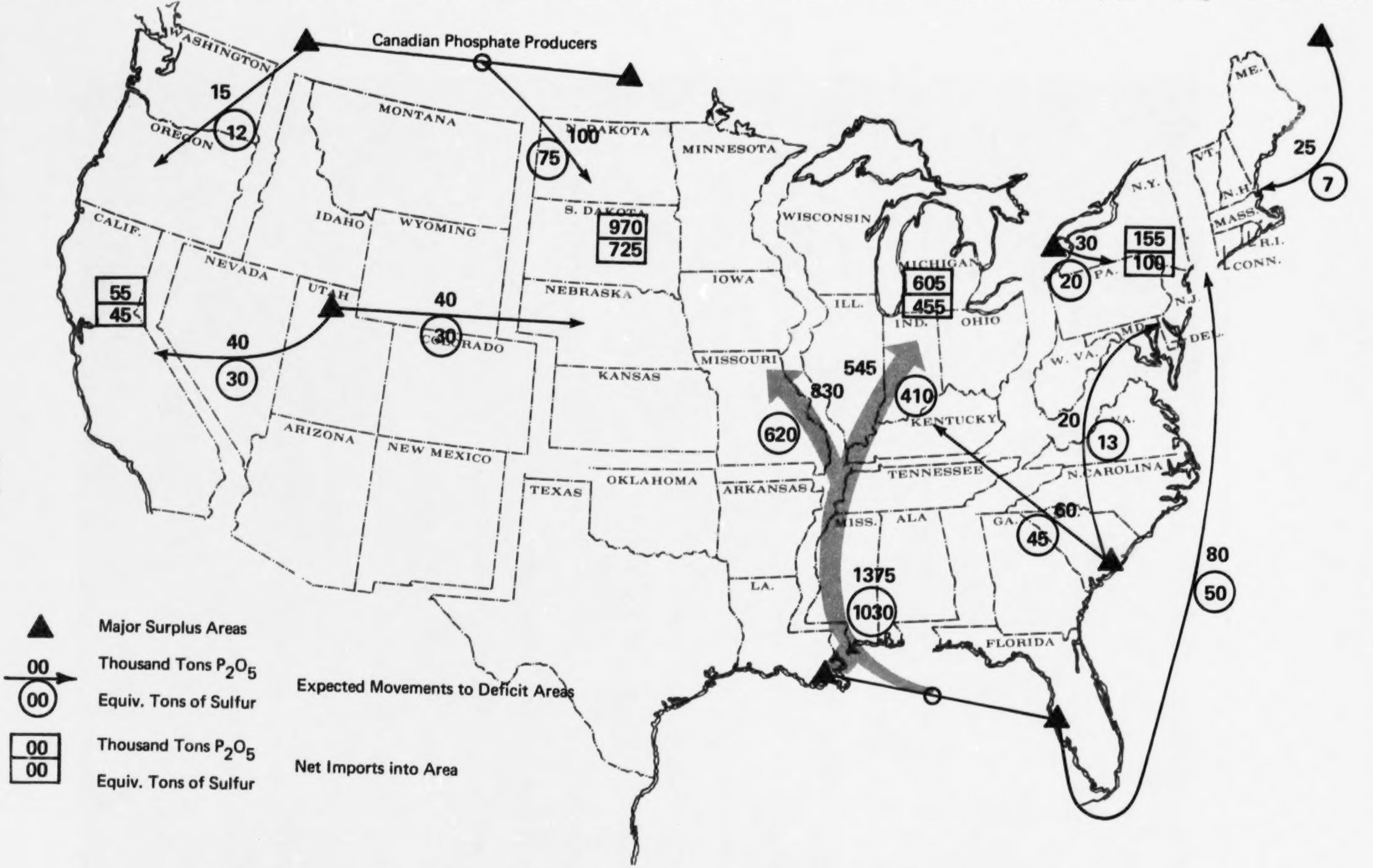

FIGURE V–3 EXPECTED MOVEMENTS OF PHOSPHATE AND EQUIVALENT SULFUR FROM SURPLUS PRODUCTION AREAS, 1971

(1000's of Short Tons)

River to the Corn Belt. In the past five years, a few phosphate projects have been located along the lower or upper Mississippi River areas so as to be located nearer to the large Midwest market. In these cases, phosphate rock is transported from the phosphate rock fields in Florida through the port of Tampa and thence by barge across the Gulf and to the River-oriented plant site. While the total delivered cost for phosphate rock is considerably higher for these river-based facilities than for the plants located in the Florida rock mining area, these higher costs are partially offset by a lower transport cost for sulfur and/or by lower outbound costs for the finished product.

Figure V-4 proposes the likely location for a phosphate fertilizer project destined to primarily serve the upper Midwest market and which would obtain its sulfuric acid from coal-derived pyrite. The map shows the general location of the high-pyrite-content coals, the increase in phosphate fertilizer consumption estimated for each of the agricultural regions over the next ten-year period (1966-1976), and the general area where the pyrite-based facility should be. In brief, we believe that the best location would lie between the confluences of the Ohio and Missouri rivers with the Mississippi. For specific estimating purposes, we have chosen Cairo, Illinois, although no attempt was made in this study to determine precisely that Cairo was the best location. For example, the St. Louis area would probably deserve careful consideration as an alternative production point.

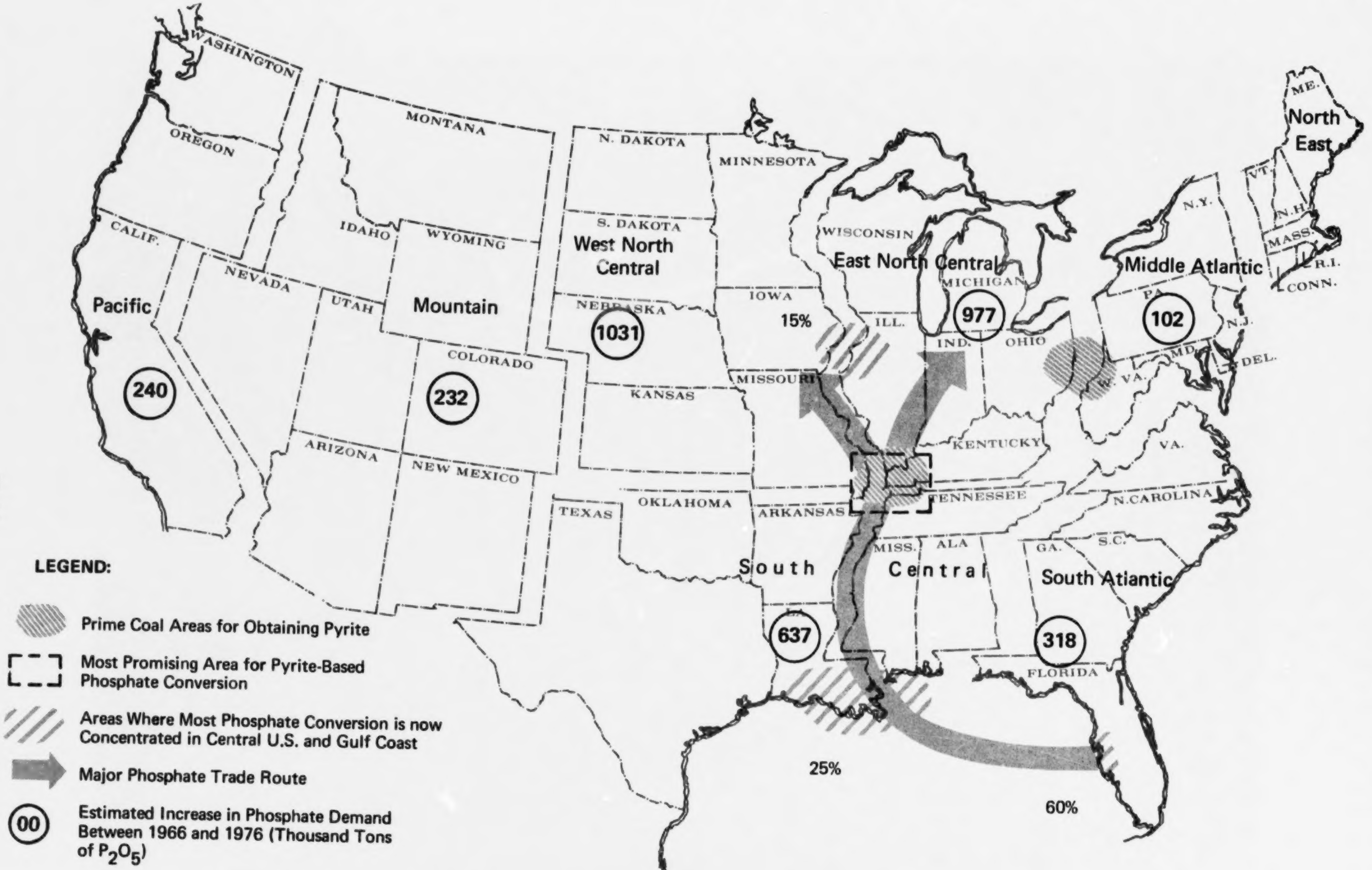

FIGURE V–4 INCREASED PHOSPHATE FERTILIZER DEMAND BETWEEN 1966 AND 1976, BY AREA WITH EXISTING PHOSPHATE SUPPLY ROUTES VERSUS LIKELY LOCATION FOR PHOSPHATE PROJECT BASED UPON PYRITE FROM COAL

As Figure V-4 shows, the two coal-producing areas which are likely to generate a sufficient quantity of pyrite to support a 1,500-ton-per-day sulfuric acid plant are the coal fields in western Pennsylvania-eastern Ohio, and Southern Illinois. Since the proposed location for the phosphate conversion facility lies near the southern Illinois area, we believe that southern Illinois coals would probably be the best source of pyrite for such a plant, assuming that these coals lend themselves to economical beneficiation.

Although Figure V-4 indicates that the growth in the phosphate fertilizer market in the West North Central and East North Central regions over the next decade will be substantial (in the order of one million tons of P_2O_5 each), one might question any near-term need for another large phosphate fertilizer project in view of the already large U.S. P_2O_5 overcapacity. While this is certainly a valid question, we believe that a few large phosphate facilities will probably be built over the next several years because:

(1) A sizable portion of the 3.2 million tons of excess P_2O_5 capacity will be moved to overseas export markets,

(2) A few large phosphate marketers are still net buyers of phosphates, and they have expressed interest in constructing additional phosphate capacity.

E. CONSIDERATION OF THE VALUE OF PYRITE FOR PYRITE MANUFACTURING IN ORDER FOR SULFUR FROM PYRITE TO BE COMPETITIVE WITH SULFUR FROM BRIMSTONE

1. Steam Requirements

About one ton of byproduct steam is required for each ton of sulfuric acid for high-analysis phosphate fertilizer manufacture; therefore, the excess steam which is usually available from a brimstone-based sulfuric acid plant is advantageously used in a modern phosphate fertilizer plant. A sulfuric acid plant based on brimstone will usually be able to export to the phosphoric acid units about 1.0-1.2 tons of low-pressure steam for each ton of 100% H_2SO_4 produced.

In a pyrite-based sulfuric acid plant, the amount of byproduct steam approaches but does not quite equal that from a brimstone plant. For pyrite feed composition No. 6 (85% pyrite, 10% coal, 5% inerts), which we have assumed in the calculations which follow, approximately one ton of steam is produced for each ton of 100% acid. Thus, we conclude that: (a) a pyrite-based sulfuric acid plant with auxiliary boilers would provide essentially the same acid-steam balance that is provided by the brimstone-based acid plants in use today, and (b) a pyrite-based plant would suffer little or no disadvantage in providing sufficient steam for phosphate manufacture.

2. Byproduct Calcine Credit

As indicated in Section III-C, there is a possibility of obtaining a byproduct credit from the sale of iron calcines. The type of acid plant being considered will generate approximately 26 units of iron per ton of product acid (98%). The marketability of the calcines and the price that could be obtained from them is open to question at present, because such details as the pyrite source, roasting operations, and specific requirements of the possible purchaser(s) are not known.

Our field work suggests that a price of $0.08-0.10 per iron unit is reasonable to expect, assuming satisfactory quality levels and an annual requirement of 250,000-300,000 tons. For a 1500-ton-per-day acid plant operating on a No. 6 feed composition, the credit would therefore amount to approximately $2.08-2.60 per ton of acid produced. The cost of shipping the calcines to the user would have to be deducted from this amount. Depending upon the distance involved, freight costs could offset a major portion of the potential credit.

Thus, because of the uncertainties described above, we believe that it is impractical at this time to assign a direct byproduct iron credit to a pyrite-based acid plant dedicated to phosphoric fertilizer operation. The possible credit to be gained, however, may be significant and should be kept in mind.

3. Determination of Preferred Source Area for Coal-Derived Pyrite

Assuming that the phosphate conversion location will be in Cairo, Illinois, it seems fairly evident that the source of the pyrite should come from southern Illinois coal rather than from western Pennsylvania-eastern Ohio coal (other factors being equal). However, to prove this point quantitatively, we have compared in Table V-2 the relative estimated costs of acid manufacture for pyrite obtained from western Pennsylvania coals versus southern Illinois coals. Table V-2 compares the manufacturing costs for sulfuric acid based on pyrite for an acid plant located at Cairo, Illinois, versus an acid plant located in western Pennsylvania but having to deliver acid to Cairo. Table V-2 also compares the acid cost for a plant producing byproduct steam with one not producing byproduct steam, since a plant in Pennsylvania shipping acid to Cairo would not be able to also ship steam to Cairo.

In brief, the findings shown in Table V-2 strongly suggest that the most economic source of sulfuric acid and steam for a phosphate plant at Cairo, Illinois, will come from pyrite obtained from southern Illinois (rather than Ohio-Pennsylvania) coals, and that the sulfuric acid plant be so designed that it generates byproduct steam. The sulfuric acid cost for a Cairo acid plant (1500-ton-per-day capacity) based upon southern Illinois pyrite is estimated at $7.63 per short ton, excluding the cost of the pyrite. If the cost of capital for this pyrite-based sulfuric acid plant is added to the straight manufacturing costs on the basis of a 10% pre-tax return on total investment, this $7.63 per ton figure must be increased by a $2.94 capital charge, raising the total "cost" to $10.57 per ton of acid (Case I-B, Table V-2).

4. Approximate Value of Pyrite Delivered to Cairo Phosphate Complex Assuming Sulfur from Pyrite Must be Competitive with Sulfur from Brimstone

The analysis which follows assumes that the price for pyrite will be determined by the cost of the now-dominant sulfur source, brimstone. It also

TABLE V-2

ALTERNATIVE DELIVERED COSTS OF PYRITE-BASED SULFURIC ACID AND STEAM FOR PHOSPHATE FERTILIZER MANUFACTURE AT CAIRO, ILLINOIS

(excluding cost of the pyrite)

BASIS:

1. Alternative Pyrite Sources - Recovered from coal beneficiation of
   - a. W. Pennsylvania-E. Ohio coals, or
   - b. Southern Illinois coals
2. Location for phosphate plant - Cairo, Illinois
3. Alternative sulfuric acid production points
   - a. Pittsburgh, Pennsylvania area, or
   - b. Cairo, Illinois
4. Sulfuric acid plant capacity - 1,500 short tons per day
5. Phosphate plant requires about 1 short ton of export (low-pressure) steam for each short ton of 100% sulfuric acid consumed.
6. Alternative cost bases for pyrite-based acid
   - a. Straight manufacturing costs plus depreciation
   - b. Manufacturing costs and pre-tax profit burden @ 10% of investment
7. Acid investment and manufacturing costs based on feed composition No. 6 (85% pyrite, 10% coal, 5% inerts).
8. Cost to produce steam with auxiliary boiler @ 2.5 times fuel value of 40¢/MM BTU or $1.00 per short ton.

TABLE V-2 (Continued)

CASE DESCRIPTIONS: I - Integrated acid-phosphate plant at Cairo, Illinois producing 1 short ton of steam/short ton acid.

- A. Pyrite from W. Pennsylvania @ $2.00/short ton premium over pyrite from southern Illinois.

- B. Pyrite from southern Illinois.

II - Acid plant at Pittsburgh not producing byproduct steam, acid shipped to Cairo @ $2.00/short ton.

BASIS - 98% H_2SO_4	CASE I-A[1]		CASE I-B[1]		CASE II[2]	
	Cairo Acid Plant-Pyrite from W. Pa.		Cairo Acid Plant-Pyrite from S. Ill.		W. Pa. Acid Plant-Pyrite from W. Pa.	
	Straight Mfg Cost	Cost & 10% Pre-Tax Return on Inv	Straight Mfg Cost	Cost & 10% Pre-Tax Return on Inv	Straight Mfg Cost	Cost & 10% Pre-Tax Return on Inv
Acid Plant Capacity - tons/day	1500	1500	1500	1500	1500	1500
annual - 1000's	495	495	495	495	511	511
Acid Plant Investment ($MM)	14.54	14.54	14.54	14.54	12.61	12.61
Ton of Feed Comp No. 6/ton 98% H_2SO_4	0.775	0.775	0.775	0.775	0.750	0.750
1. Mfg cost, excluding cost of pyrite (98% H_2SO_4)	7.63	7.63	7.63	7.63	7.00	7.00
2. Pyrite transport cost-From Pa. (2.00/T X 0.775 T/T)	1.55	1.55	--	--	--	--

TABLE V-2 (Continued)

	CASE I-A[1]		CASE I-B[1]		CASE II[2]	
	Cairo Acid Plant-Pyrite from W. Pa.		Cairo Acid Plant-Pyrite from S. Ill.		W. Pa. Acid Plant-Pyrite from W. Pa.	
	Straight Mfg Cost	Cost & 10% Pre-Tax Return on Inv	Straight Mfg Cost	Cost & 10% Pre-Tax Return on Inv	Straight Mfg Cost	Cost & 10% Pre-Tax Return on Inv
3. Acid Transportation cost from Pa.	-	-	-	-	2.00	2.00
4. Cost of steam (if not provided by acid plant) per ton of H_2SO_4	-	-	-	-	1.00	1.00
5. Cost of capital @ 10% of investment - Pre-Tax	-	2.94	-	2.94	-	2.48
Acid cost at Cairo, Illinois Excluding pyrite cost	9.18	12.12	7.63	10.57	10.00	12.48

1. Plant Type I-A, Feed Composition No. 6.

2. Plant Type II-A (no steam generation), Feed Composition No. 6.

assumes that the economics of a pyrite-based phosphate operation in Cairo, Illinois, may have to compete not only with the economics of a Cairo plant based on brimstone but also with the economics of a phosphate plant located in Baton Rouge (a typical location for some new phosphate projects now under construction) based upon brimstone.

In addition to considering the pyrite-versus-brimstone alternatives cited above, it is also important to consider the comparable cost of capital for a brimstone-based sulfuric acid plant and a pyrite-based sulfuric acid plant. If the investment costs per annual ton of sulfuric acid are higher for a pyrite plant than for a brimstone plant, which is the case, this higher capital requirement should be reflected as a cost item in the comparison. The discussion which follows, therefore, takes into account: (a) straight manufacturing costs for these two acid sources and (b) straight manufacturing costs plus a cost of capital equivalent to 10% pre-tax return on fixed investment.

a. Manufacturing Costs for Sulfuric Acid Based Upon Brimstone

Table V-3 presents our estimates of sulfuric acid manufacturing costs based upon elemental sulfur (brimstone) for both a Baton Rouge and Cairo, Illinois location. Plant capacity has been selected at 1500 tons per day and the sulfur price at $38.00 per long ton f.o.b. mine (the approximate price as of December 1967) but adjusted for the transport cost between the mine area in southern Louisiana and the alternative destinations of Baton Rouge and Cairo. The estimates in Table V-3 further assume that the investment cost and operating cost

TABLE V-3

MANUFACTURING COST FOR SULFURIC ACID (100% BASIS) FROM BRIMSTONE (ELEMENTAL SULFUR) AT CAIRO, ILLINOIS AND BATON ROUGE, LOUISIANA

(per short ton)

BASIS:
1. 1500-ton-per-day acid plant
2. Sulfur price \$38.00/LT f.o.b. mine[1]
3. Delivered costs of sulfur
   a. Baton Rouge: \$39.50/LT (\$35.25/short ton)
   b. Cairo: \$42.20/LT (\$37.70/short ton)
4. Investment, labor, and utility costs same for both locations

	Baton Rouge	Cairo
Plant Capacity - Short tons/day	1,500	1,500
- Short tons/year (350 days)	525,000	525,000
Fixed Investment	5.8 MM	5.8 MM
Manufacturing Costs -		
Variable Costs:		
Sulfur @ 0.34 T/Y	12.00	12.82
Power @ 1.5 KWH	0.02	0.02
Catalyst, operating supplies	0.08	0.08
	12.10	12.92
Semi-Variable and Fixed Costs		
Operating labor - 9 men (\$67 M)	0.13	0.13
Supervision - 3 men (\$29 M)	0.05	0.05
Overhead @ 100% operating labor (\$96 M)	0.18	0.18
Maintenance @ 3% investment	0.32	0.32
Taxes and insurance @ 2% investment	0.22	0.22
Depreciation (10 years)	1.10	1.10
	2.00	2.00
Total Cost per Ton	14.00	14.92
(Cost of capital @ 10% of Investment Pre-Tax)	(1.10)	(1.10)

1. December 1967 price. On March 1, 1968, Gulf Coast sulfur prices were increased by \$3.00 per long ton to \$41.

Source: Arthur D. Little, Inc., estimates.

are the same for both locations, excluding the cost of sulfur itself. As the table shows, the manufacturing cost for sulfuric acid at Baton Rouge is $14.00 per ton of 100% acid versus $14.92 for the Cairo location. If the cost of capital at 10% of investment pre-tax is added to these manufacturing cost figures, the total cost would increase by $1.10 per ton for each location.

b. Value of Pyrite Delivered to Cairo, Illinois, Assuming Brimstone Price of $38.00 per Long Ton, f.o.b. Mine

Table V-4 presents the calculations for determining the net value of pyrite at the hypothetical phosphate plant at Cairo, Illinois, under two conditions:

Case A: That the pyrite-based plant at Cairo would be competitive in cost with a brimstone-based plant at Baton Rouge, Louisiana.

Case B: That the Cairo pyrite-based phosphate plant must be competitive in cost with a brimstone-based phosphate plant located at Cairo.

In order to determine the pyrite value, we took into account the difference in inbound and outbound cost of materials for each alternative. For purposes of simplicity, we assumed that all of the finished phosphatic fertilizer would be in the form of diammonium phosphate, one of the more popular high-analysis fertilizers. As Table V-4 shows, the net value of pyrite (delivered) is $2.42 per ton if the Cairo plant must compete against a Baton Rouge phosphate project using brimstone. However, if the pyrite-based Cairo operation competes

TABLE V-4

APPROXIMATE DOLLAR VALUE OF PYRITE DELIVERED TO CAIRO, ILLINOIS, PHOSPHATE COMPLEX CONSIDERING ALTERNATIVE LOCATIONS AND BRIMSTONE AS AN ALTERNATIVE SUPPLY OF SULFUR

(value determined by straight costs only; return on invested capital not included)

		Baton Rouge Location (Based on Brimstone)			Cairo, Illinois Location — Brimstone Option			Cairo, Illinois Location — Pyrite Option		
		Product	Per Ton H_2SO_4 (100%)	Per Ton P_2O_5 (100%)	Product	Per Ton H_2SO_4 (100%)	Per Ton P_2O_5 (100%)	Product	Per Ton H_2SO_4 (100%)	Per Ton P_2O_5 (100%)
1. **Phosphate Rock** (68 BPL)	5.00/NT f.o.b. Fla + 3.15 frt.	8.15	-		10.85*			10.85*		
	3.47 T/T P_2O_5			28.30			37.60			37.60
2. **Elemental Sulfur**	38.00/LT f.o.b. La. + 1.50 frt.	39.50			42.20			-		
	.306 LT/T H_2SO_4		12.10			12.92			-	
	.827 LT/T P_2O_5			32.60			34.90			-
3. **H_2SO_4** Mfg Cost, excl matl's cost and profit			2.00			2.00			7.63	
(Basis: 1500 TPD) 2.7 NT H_2SO_4/T P_2O_5				5.40			5.40			20.60
4. **Phosphoric Acid** Mfg Cost, excl matl's cost and profit (Basis: 600 TPD P_2O_5 - 1500 TPD H_2SO_4)			-	12.80			12.80			12.80
5. **Ammonia** for Diammonium - 0.23 T/T @ $30 f.o.b. B.R.		30.00			38.00			38.00		
Phosphate (DAP) Manufacture 0.5 T NH_3/T P_2O_5 as 18-46-0				15.00			19.00			19.00
6. **DAP** Mfg cost, excl matl's and profit		6.20			6.20			6.20		
(Basis: 1200 TPD 18-46-0)				13.50			13.50			13.50
7. **Barge Freight**/Ton DAP to typical Midwest market		4.00			2.00			2.00		
location (Dubuque, Iowa)				8.70			4.35			4.35
8. **Delivered Cost** of P_2O_5 in form of DAP, excluding return on investment				116.30			127.55			107.85

		CASE A B.R. Brimstone vs Cairo Pyrite	CASE B Cairo Brimstone vs Cairo Pyrite
9. **Allowable Price for Pyrite****	per ton P_2O_5	8.45	19.70
(Delivered to Cairo, Illinois)	per ton H_2SO_4	3.13	7.30
	per ton Pyrite (45.7% S)	2.42***	5.65***

* Additional freight from Baton Rouge to Cairo $2.70/NT

** 0.775 ton pyrite/ton H_2SO_4, based on feed composition No. 6

*** Price that could be paid for pyrite (including freight) at Cairo to permit a pyrite-based operation to be competitive with a brimstone-based facility.

with a brimstone-based phosphate operation also at Cairo, the potential value of the pyrite is considerably increased -- to \$5.65 per ton. If the pyrite were obtained from Western Pennsylvania, water transportation costs alone would amount to approximately \$2.00 per ton, making the potential f.o.b. price (excluding additional freight costs from preparation plant to dockside) of the pyrite \$0.42 to \$3.65 per ton. These pyrite values do not take into account the cost of capital associated with the higher investment which a pyrite-based sulfuric acid plant will require. A discussion of this aspect is presented below.

c. Value of Pyrite at Cairo, Illinois, Taking into Account Cost of Capital Associated with Sulfuric Acid Plant

Table V-5 adjusts the values presented in Table V-4 for the difference in cost of capital associated with the different investment required for each type of acid plant. Since the investment for a brimstone-based sulfuric acid plant is lower than that for an equivalent sized pyrite-based sulfuric acid plant, the pyrite values previously shown must be adjusted downward to reflect this investment differential.

In Table V-5, Case A-I and Case B-I summarize the data of Table V-4. Case A-II and Case B-II show how the value for pyrite adjusts downward when cost of capital, based upon 10% pre-tax return on fixed investment, is taken into account. The higher investment cost per annual ton associated with a pyrite-based plant results in a capital cost penalty of about \$1.84 per ton of 100% sulfuric acid or \$1.42 per ton of pyrite (0.775 ton of pyrite is required per ton of 100% H_2SO_4). Therefore, the \$2.42 value shown in Case A-I moves downward

TABLE V-5

APPROXIMATE VALUE OF IRON PYRITE DELIVERED TO CAIRO, ILLINOIS, PHOSPHATE COMPLEX, UNDER SELECTED CONDITIONS

(dollars per ton of 100% H_2SO_4)

CASE A Cairo pyrite-based acid-phosphate plant competes with Baton Rouge brimstone-based acid phosphate complex;

I Brimstone cost @ $39.50/long ton delivered Baton Rouge; sulfuric acid production costs include straight manufacturing costs only

II Sulfuric acid production costs include straight manufacturing costs + 10% pre-tax return on fixed plant investment

CASE B Cairo pyrite-based acid plant competes with Cairo brimstone-based acid plant;

I Straight costs only

II Straight costs only + 10% return on fixed plant investment

Basis for Investment Burden (@ 10% pre-tax return on fixed investment):

Brimstone plant	$1.10/ton of acid
Pyrite-based plant	$2.94/ton of acid
Capital Cost Differential (Penalty) of Pyrite-based acid plant	$1.84/ton of acid

	CASE A		CASE B	
(Location of competing brimstone-based plant)	(Baton Rouge, La.)		(Cairo, Illinois)	
	A-I	A-II	B-I	B-II
Allowable price for sulfuric acid before cost of pyrite and before cost of capital (Table V-4)	$3.13	$3.13	$7.30	$7.30
Less: Investment cost penalty of pyrite-based acid plant	-	1.84	-	1.84
Allowable price for pyrite delivered to Cairo - per ton H_2SO_4	3.13	1.29	7.30	5.46
- per ton pyrite[1] (45.7% S)	2.42	1.00	5.65	4.23

---

1. 0.775 ton of pyrite (85% Feed Composition No. 6) will produce 1 ton of 100% H_2SO_4.

to $1.00 per ton in Case A-II. Likewise, the $5.65 figure in Case B-1 drops to $4.23 in Case B-II.

It should be emphasized that the above price estimates are on a delivered ton of pyrite; freight costs would have to be deducted to arrive at a net-back price for the pyrite at the source (i.e., the coal beneficiation plant). Since the source of pyrite has not been established, precise freight costs cannot be developed. However, we are reasonably sure that water transportation rates between Pittsburgh and Cairo are roughly $2.00 per ton. If the pyrite were obtained from southern Illinois, freight costs would presumably be less than if they originated in western Pennsylvania. If we assume a token overland freight cost of $0.50 per ton from coal field (preparation plant) to dockside in Pennsylvania or from coal field to acid plant in southern Illinois, the net cost of pyrite to the operations described above approximates the starred figures in Table V-6.

It thus becomes apparent that the net price payable to a coal company for an 85% pyrite feed, assuming the manufacturing situation described earlier, may range from a negative value ($1.50) to about $5.15/ton.

A significant tonnage of coal must be processed to obtain a ton of acceptable pyrite feed material; in the earlier section covering process economics, we reported an industry estimate that under certain conditions approximately 17 tons of Kittanning coal would have to be processed to obtain one ton of 85% pyrite feed. If this ratio applied to all coals in the regions being considered (we are sure it does not), the maximum break-even cost that a coal company could incur

TABLE V-6

NET COST OF PYRITE TO CAIRO AND BATON ROUGE LOCATIONS

A. Before Cost of Capital

Baton Rouge Brimstone vs Cairo Pyrite ($2.42/ton allowable)			Cairo Brimstone vs Cairo Pyrite ($5.65/ton allowable)	
Pyrite from S. Illinois	Pyrite from Pennsylvania		Pyrite from S. Illinois	Pyrite from Pennsylvania
-	2.00/ton	Water Transp.	-	$2.00/ton
0.50	0.50	Land Transp.	0.50	0.50
$0.50/ton	$2.50/ton	Total Freight	$0.50/ton	$2.50/ton
$1.92/ton*	$0.08/ton*	Net Pyrite Cost	$5.15/ton*	$3.15/ton*

B. After Cost of Capital (10% pre-tax return)

Baton Rouge Brimstone vs Cairo Pyrite ($1.00/ton allowable)			Cairo Brimstone vs Cairo Pyrite ($4.23/ton allowable)	
Pyrite from S. Illinois	Pyrite from Pennsylvania		Pyrite from S. Illinois	Pyrite from Pennsylvania
-	2.00/ton	Water Transp.	-	$2.00/ton
0.50	0.50	Land Transp.	0.50	0.50
$0.50/ton	$2.50/ton	Total Freight	$0.50/ton	$2.50/ton
$0.50/ton*	($1.50/ton*)	Net Pyrite Cost	$3.73/ton*	$1.73/ton*

in beneficiating its coal to generate 85% pyrite feed would be

$\frac{\$3.73\text{/ton pyrite}}{17\text{ tons coal/ton pyrite}}$, or \$0.22/ton of coal, including the 10% pre-tax return on investment allowance.

d. Value of Pyrite Delivered to Cairo, Adjusted for Changing Cost of Brimstone

Figure V-5 summarizes the results of our study concerning the value of pyrite if used for providing sulfuric acid to a large phosphate fertilizer project at Cairo, Illinois. Since the future price for brimstone is perhaps the most critical and uncertain variable in the equation, we have shown how our estimates of pyrite value change as sulfur price varies between \$28.00 per long ton to \$48.00 per long ton f.o.b. mine (December 1967 price = \$38.00 per long ton, f.o.b. mine). Figure V-5 also shows how the pyrite valuation changes according to: (1) the location of the competitive brimstone-based phosphate operation (Baton Rouge or Cairo) and (2) straight manufacturing costs versus straight manufacturing cost plus a capital charge (10% pre-tax return on fixed investment).

The most severe test to a pyrite-based project is Case A-2 (Figure V-5). Under this variation, a pyrite-based sulfuric acid plant at Cairo must: (a) compete against a brimstone-based phosphate plant located in Baton Rouge, and (b) compete on the basis of manufacturing cost plus a surcharge for fixed investment. As previously discussed, the theoretical pyrite value under this case would amount to about \$1.00 per ton (delivered to Cairo) at a sulfur price of \$38.00 per long ton, f.o.b. mine. If brimstone prices dropped to \$28.00

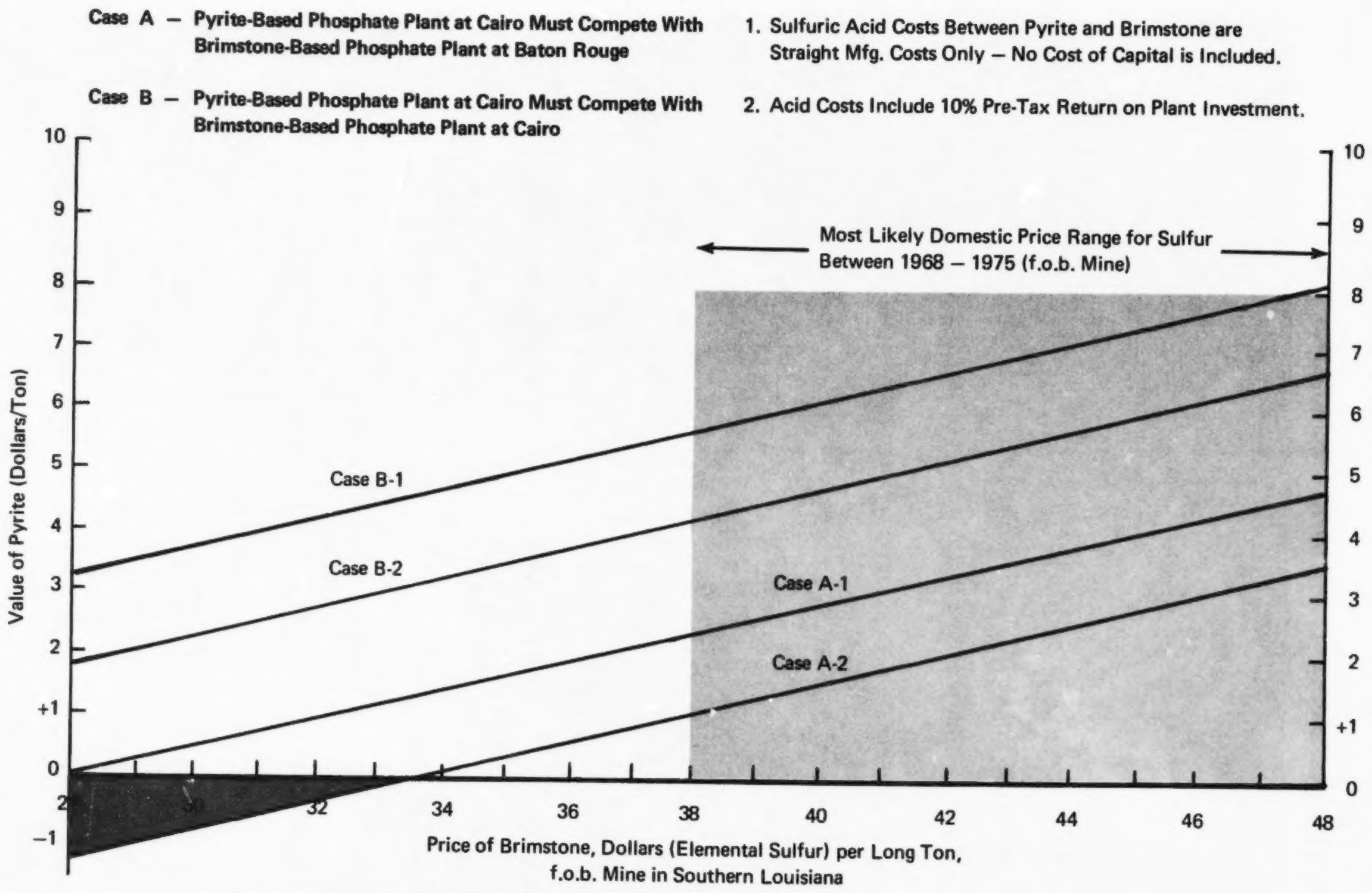

FIGURE V-5 ESTIMATED VALUE OF PYRITE FOR SUPPLYING SULFURIC ACID TO PHOSPHATE FERTILIZER PLANT AT CAIRO, ILLINOIS AS A FUNCTION OF ---
1. Prevailing Price of Brimstone (Elemental Sulfur)
2. Location of Brimstone — Based Phosphate Plant — Baton Rouge, La., or Cairo, Ill.
3. Comparing Straight Manufacturing Costs Only Versus Manufacturing Costs Plus a Capital Charge (Assumed 10% Pre-Tax Return on Fixed Investment)

per long ton, the pyrite would represent a negative value at Cairo of $1.27 per ton. Conversely, if brimstone prices rise to $48.00 per long ton, and other conditions are favorable, the value of pyrite delivered to Cairo could increase to about $8.00 per ton (Case B-I).

e. Allowance for Comparative Investment Risks

The foregoing discussion has indicated that in a pyrite-based fertilizer complex the investment required for the sulfuric acid plant is considerably higher than that for a brimstone-based acid plant. A 1500-TPD pyrite-based acid plant (Type I-A) requires a fixed investment of $14.54 million versus $5.8 million for a brimstone-based plant -- a ratio of 2.5 to 1. Because of this significantly larger investment, the manager of the project will be concerned over the rate at which the investment is returned, particularly in view of the possibility of changing prices for either raw materials or finished products. For the foreseeable future elemental sulfur will continue to be the basis upon which sulfur prices are set. We believe that sulfur price increases beyond $45-50/long ton are unlikely over the next five years. Moreover, we believe that price decreases after that time are a definite possibility as a result of new sulfur sources, or alternatives to sulfur use being developed.

With these considerations in mind, along with the higher capital cost of a pyrite-based acid plant, it is reasonable for a potential manager to view a pyrite-based facility as having a "down-side risk" (decline in brimstone price) and therefore to want to recover his investment as quickly as possible -- more quickly than if his plant were based on brimstone supply.

For example, he might wish to recover his capital costs twice as rapidly as he would if the operation were based on brimstone. He would therefore double his target rate of return to see what impact this would have on his expected costs, e.g., for raw materials. The calculations shown in Table V-7 follow this line of reasoning, assuming a 10% pre-tax return on investment (ROI) for a brimstone-based plant and comparing this with a 15% and 20% ROI requirement for a pyrite-based facility (basic assumption taken from Table V-5).

Thus, with the allowance for a down-side risk applied to a pyrite-based operation, the theoretical price payable for pyrite raw material becomes even lower.

Obviously, each company having an interest in developing a new source of sulfur values will view its situation differently. Market position, raw material sources, timing requirements, investment analysis procedures, and corporate relationships are but some of the factors that will have to be taken into account.

It is therefore difficult to assess which of the conditions shown in Figure V-5, along with the modifications just presented, would be the most representative for a specific project. If brimstone were difficult to obtain, the value of pyrite would probably follow one of the upper curves in Figure V-5. If the reverse were true and sulfur prices began to decline, pyrite values would be reduced accordingly.

In either case, it should be kept in mind that the pyrite price expressed in terms of per ton of coal credit or debit to the coal company is relatively small (minus 9¢ to plus 22¢ per ton, allowing for transportation and assuming a straight 10% ROI requirement for all alternatives) compared with the estimated credits obtained as the result of low-sulfur (depyritized) coal preparation ($1.10-1.20 per ton). Hence, depending upon the costs associated with beneficiation of the coal and preparation of the pyrite feed, it may be feasible for a coal company to bear at least a significant proportion of these costs, and in effect, thereby reduce the potential cost of pyrite to the acid plant.

TABLE V-7

ALLOWABLE PYRITE PRICE FOR DIFFERENT RETURN ON INVESTMENT REQUIREMENTS

	Pre-Tax ROI		
	10%	15%	20%
Investment burden of pyrite plant - $/ton acid	$2.94	$4.41	$5.88

	CASE A-II (Baton Rouge, Louisiana)		CASE B-II (Cairo, Illinois)	
	15%	20%	15%	20%
Acid price before cost of pyrite and cost of capital (Table V-5)	$3.13	$3.13	$7.30	$7.30
Less Investment burden shown above for 15% and 20% ROI minus $1.10/ton cost for brimstone plant	-3.31	-4.78	-3.31	-4.78
Allowable price of pyrite per ton of acid	(0.18) negative	(1.65) negative	3.99	2.52
Allowable price of pyrite per ton of pyrite (0.775 basis)	(0.14) negative	(1.28) negative	3.09	1.95
Allowable price of pyrite per ton of coal (assuming 17 tons of coal per ton of pyrite)	(0.01) negative	(0.075) negative	0.18	0.115

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APPENDIX A

COMPUTER PROGRAM TO DETERMINE PYRITE PRICE AS A FUNCTION OF BRIMSTONE PRICES IN MAKING SULFURIC ACID

(basic language)

```
5 READ S
10 FOR I = 1 TO 3
20 FOR J = 1 TO 4
30 READ P(I,J), R(I,J)
40 NEXT J
50 NEXT I
55 FOR I = 1 TO 3
60 FOR J = 1 TO 4
62 IF J = 1 THEN 75
63 IF J = 2 THEN 80
66 IF J = 3 THEN 100
70 IF J = 4 THEN 120
75 LET Z(I,J) = .15*P(I,J)/165000
77 LET B(J) = .336*S + 6.37
79 GO TO 180
80 LET Z(I,J) = .15*P(I,J)/330000
90 LET B(J) = 4.46 + .336*S
95 GO TO 180
100 LET Z(I,J) = .15*P(I,J)/495000
110 LET B(J) = 3.75 + .336*S
115 GO TO 180
120 LET Z(I,J) = .15*P(I,J)/825000
130 LET B(J) = 3.51 + .336*S
180 LET A(I,J) = R(I,J) + Z(I,J)
190 LET M(I,J) = B(J) - A(I,J)
200 NEXT J
210 NEXT I
220 PRINT "THE DATA BELOW ARE FOR THE FOLLOWING CONDITIONS"
222 PRINT "LINE 1 500 TPD FEED 4"
224 PRINT "LINE 2 1000TPD FEED 4"
226 PRINT "LINE 3 1500TPD FEED 4"
228 PRINT "LINE 4 2500TPD FEED 4"
230 PRINT "LINE 5 500 TPD FEED 6"
232 PRINT "LINE 6 1000TPD FEED 6"
234 PRINT "LINE 7 1500TPD FEED 6"
236 PRINT "LINE 8 2500TPD FEED 6"
238 PRINT "LINE 9 500TPD FEED 8, ETC"
239 PRINT
244 PRINT "THE DELIVERED COST OF SULFUR IS" S "$/LONG TON"
246 PRINT
247 PRINT "ALL FIGURES IN $/SHORT TON OF ACID"
248 PRINT
```

```
250 PRINT "MFG COST","MFG COST","MAX PYRITE"
255 PRINT "BRIMSTONE","PYRITE","DELIV COST"
260 PRINT " ","W/O RAW MATL", "FOR MFG COST=S"
265 PRINT
300 FOR I = 1 TO 3
310 FOR J = 1 TO 4
320 PRINT B(J), INT(100*A(I,J)+.5)/100, INT(100*M(I,J)+.5)/100
330 NEXT J
340 NEXT I
900 DATA 40
903 REM DATA ORDER IS (500TPD,FEED 4), 1000TPD, FEED 4), ETC
905 REM NEXT LINE (500TPD, FEED 6), (1000TPD, FEED 6), ETC
910 DATA 6.1E6,11.34,10.19E6,8.27,13.5E6,7.07,21.E6,6.88
920 DATA 6.59E6,11.76,10.96E6,8.63,14.54E6,7.63,22.65E6,7.2
930 DATA 7.E6,12.15,11.66E6,9.31,15.42E6,7.9,24.1E6,7.72
999 END
```

APPENDIX B

OXYGEN ENRICHMENT

It has been proposed that oxygen enrichment might be considered for roasting of low-grade (high-coal-content) pyrite to produce higher-strength SO_2 gas for acid manufacture. Oxygen enrichment of the air for roasting would not change the SO_2-CO_2 ratio or the SO_2-H_2O ratio in the gas as these ratios are a function of the S - C and the S - H_2 ratios in the pyrite-coal feed material. However, oxygen enrichment would, by virtue of less nitrogen dilution, make it possible to produce a gas of higher SO_2 content.

To evaluate the merits of oxygen enrichment the following process and economic study has been made. Consider a pyrite roasting-contact sulfuric acid plant designed to process pyrite plant feed composition No. 2 (90% pyrite, 5% coal, 5% inerts). By adding the appropriate amount of oxygen to the air, lower-grade pyrite plant-feeds can be processed in this plant with no increase in gas volume or no decrease in SO_2 concentration in the gas. Process calculations have been made using this approach and the resulting process data is presented in Table B-1.

The daily oxygen requirements for the different grades of pyrite plant feeds and for the different plant capacities (based on the oxygen requirements presented in Table B-1) are given in Table B-2. The cost of the oxygen is also given in Table B-2, expressed in terms of dollars per ton of 98% product acid.

These oxygen-cost figures were determined from the oxygen requirements as presented in Table B-2 and on the basis of the cost of tonnage oxygen

TABLE B-1

Oxygen Enrichment Process Data

	Pyrite Plant Feed Composition Number										
	2	4		6		8		10		12	
% Pyrite	90	80		85		70		70		65	
% Coal	5	7		10		10		15		23	
% Inerts	5	13		5		20		15		12	
Air Requirements	Air Only	Air Only	O_2 Enr. Air	Air Only	O_2 Enr. Air	Air Only	O_2 Enr. Air	Air Only	O_2 Enr. Air	Air Only	O_2 Enr. Air
Cubic Ft. Air/Ton (98%) Acid	71,600	77,700	70,000	82,900	68,200	87,900	66,700	102,500	62,500	125,000	54,500
Oxygen Addition											
Pounds Oxygen/Ton (98%) Acid	0	0	135	0	260	0	364	0	665	0	1230
Feed Oxidation Product Gases											
Volume - Cu. Ft. / Ton (98%) Acid	69,000	75,500	69,000	80,700	69,000	86,000	69,000	99,500	69,000	125,000	69,000
Analyses — % by Volume											
SO_2	12.4	11.4	12.4	10.6	12.4	10.0	12.4	8.6	12.4	6.8	12.4
CO_2	2.4	3.5	3.8	4.3	5.1	5.0	6.2	6.4	9.2	8.3	15.0
O_2	2.0	2.0	2.2	2.0	2.3	1.9	2.4	1.9	2.8	1.9	3.5
N_2	82.1	81.5	79.9	81.1	77.9	80.9	76.2	80.2	71.4	79.2	62.3
H_2O	1.1	1.6	1.7	2.0	2.3	2.2	2.8	2.9	4.2	3.8	6.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TABLE B-2

Oxygen Requirements vs. Plant Capacity and Pyrite Feed Composition

		Pyrite Plant Feed Composition Number											
		2		4		6		8		10		12	
Pounds Oxygen Required/Ton (98%) Acid		0		135		260		364		665		1230	
Plant Type		I	II	I	II	I	II	I	II	I	II	I	II
Oxygen Requirement - Tons O_2/Day													
Capacity - TPD (98%) Product Acid													
Plant Type I	**Plant Type II**												
250	258	0	0	16.9	17.4	32.5	33.6	45.5	47.0	83.1	83.2	153.75	158.5
500	517	0	0	33.8	34.9	65.0	67.2	91.0	94.0	166.2	167.0	307.5	318.0
1000	1033	0	0	67.6	69.8	130.0	134.5	182.0	188.0	332.4	333.0	615.0	635.0
1500	1550	0	0	101.4	104.8	195.0	201.5	273.0	282.0	498.6	500.0	922.5	953.0
2500	2583	0	0	169.0	174.8	325.0	336.0	455.0	470.0	831.0	833.0	1537.5	1590.0
Oxygen Costs - Dollars/Ton (98%) Acid													
Capacity - TPD (98%) Product Acid													
Plant Type I	**Plant Type II**												
250	258	0	0	-	-	-	-	-	-	5.12	4.95	8.17	8.14
500	517	0	0	-	-	2.08	2.08	2.75	2.73	4.34	4.12	6.43	6.30
1000	1033	0	0	1.08	1.07	1.81	1.77	2.30	2.28	3.36	3.25	4.85	4.80
1500	1550	0	0	0.99	0.99	1.61	1.56	2.00	1.97	2.81	2.72	4.26	4.24
2500	2583	0	0	0.88	0.86	1.32	1.30	1.59	1.59	2.38	2.30	4.00	4.00

as shown on Figure B-1, which gives the relationship between oxygen cost and oxygen plant capacity. These costs are based on purchased price from an adjoining oxygen plant.

The total processing costs for producing sulfuric acid from the six different grades of pyrite plant feed and for capacities from 250 to 2500 tons per day of acid were presented in Table III-35. This is for plants which use air only for roasting the pyrite. Using these total processing costs figures as a standard for comparative purposes, it is possible to arrive at an approximate total processing cost for plants using oxygen enrichment. As was discussed at the beginning of this Appendix, the study has been based on a plant designed to produce acid using pyrite plant feed No. 2 and then adding oxygen to the air so as to be able to process lower grade (less pyrite-more coal) pyrite plant-feed and still maintain the same roaster gas volumes and SO_2 strength. Therefore, if the total processing costs for pyrite plant feed composition No. 2 are used as a basic standard and to these costs are added the oxygen costs as presented in Table B-2, the resultant total should represent a reasonable approximation of the total processing costs for an oxygen enrichment plant. The results of this type of a computation are presented in Table B-3.

As indicated by the cost figures in Table B-3, the use of oxygen to enrich the air is not a practical approach to reducing the total processing costs. A possible reduction in processing cost is indicated only for large tonnages, 1500 - 2500 tons of acid per day, and for pyrite plant-feed compositions numbers 10 and 12. For these low-grade pyrite feeds, however, the total processing costs

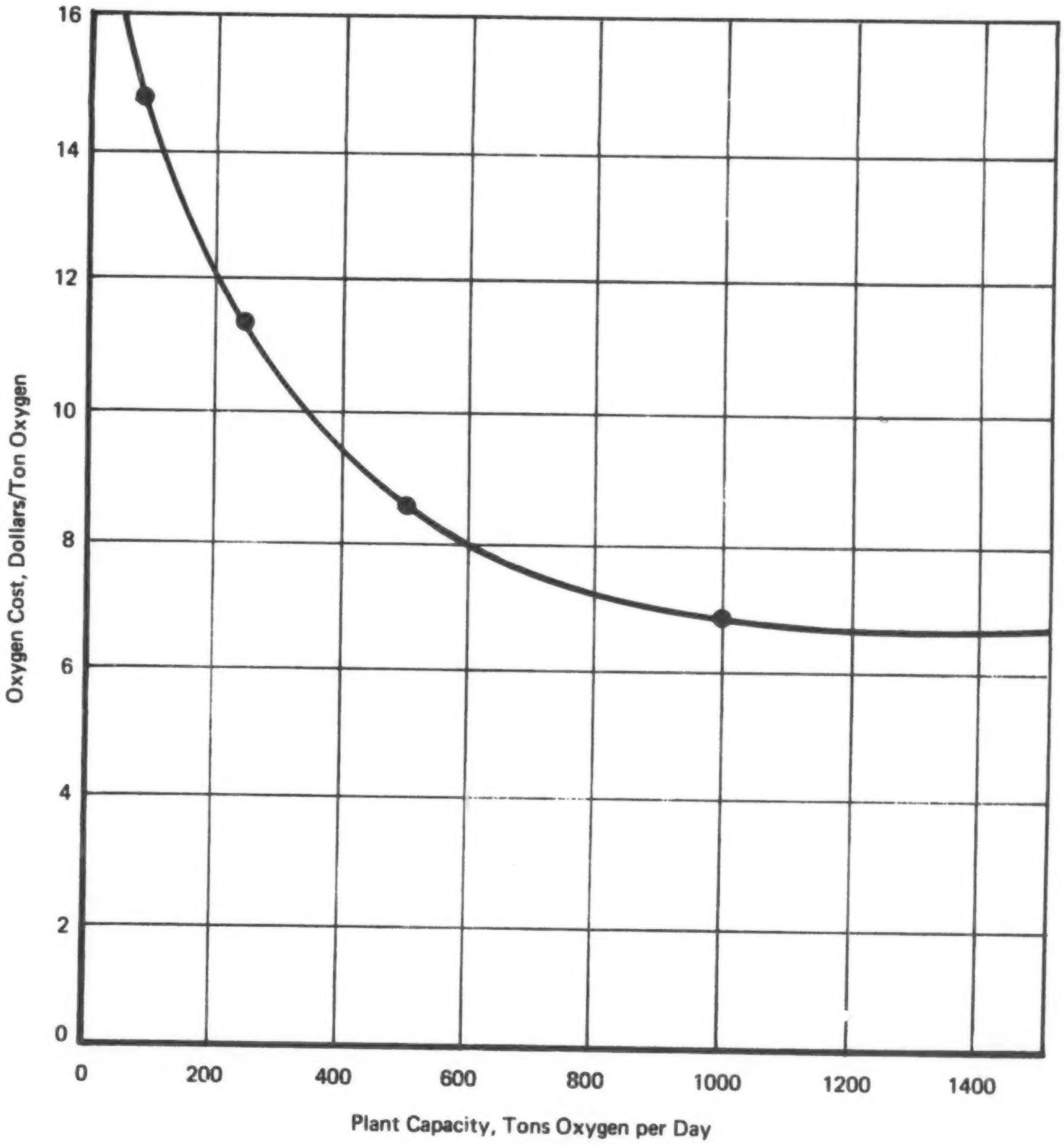

FIGURE B-1 OXYGEN COST VERSUS PLANT CAPACITY
(Power at 8 mills/KWHr)

TABLE B-3

Total Processing Costs for Oxygen Enrichment Plants
Dollars per Ton (98%) Acid

	Pyrite Plant Feed Composition Number										
	2	4		6		8		10		12	
	Air Only	Air Only	O_2 Enr. Air	Air Only	O_2 Enr. Air	Air Only	O_2 Enr. Air	Air Only	O_2 Enr. Air	Air Only	O_2 Enr. Air
Plant Type IA **Capacity - TPD (98%) Acid**											
250	18.11	-	-	-	-	-	-	21.61	23.23	24.52	26.28
500	10.74	-	-	11.76	12.82	12.15	13.49	13.66	15.08	15.74	17.17
1000	7.75	8.27	8.83	8.63	9.56	9.31	10.05	10.22	11.11	12.29	12.60
1500	6.60	7.07	7.59	7.63	8.21	7.90	8.60	8.97	9.41	11.53	10.86
2500	6.20	6.88	7.08	7.20	7.53	7.72	7.79	8.74	8.58	11.14	10.20
Plant Type IB **Capacity - TPD (98%) Acid**											
250	18.64	-	-	-	-	-	-	22.42	23.76	25.40	26.81
500	11.33	-	-	12.47	13.41	12.88	14.08	14.64	15.67	16.86	17.76
1000	8.34	8.91	9.42	9.34	10.15	10.07	10.64	11.10	11.70	13.42	13.19
1500	7.20	7.72	8.19	8.34	8.81	8.68	9.20	9.87	10.01	12.65	11.46
2500	6.80	7.54	7.68	7.92	8.12	8.49	8.39	9.64	9.18	12.29	10.80
Plant Type IIA **Capacity - TPD (98%) Acid**											
258	15.63	-	-	-	-	-	-	19.23	20.58	22.21	23.77
517	9.47	-	-	10.52	11.55	10.90	12.20	12.62	13.59	14.65	15.77
1033	6.92	7.43	7.99	7.82	8.69	8.46	9.20	9.41	10.17	11.62	11.72
1550	5.92	6.38	6.91	7.00	7.48	7.32	7.89	8.35	8.64	10.76	10.16
2583	5.51	6.20	6.37	6.53	6.81	7.03	7.08	8.02	7.81	10.32	9.51
Plant Type IIB **Capacity - TPD (98%) Acid**											
258	16.62	-	-	-	-	-	-	20.52	21.57	23.80	24.76
517	10.44	-	-	11.67	12.52	12.11	13.17	13.96	14.65	16.45	16.74
1033	7.91	8.55	8.98	9.00	9.68	9.70	10.19	10.86	11.16	13.49	12.71
1550	6.93	7.51	7.92	8.21	8.49	8.58	8.90	9.84	9.65	12.70	11.17
2583	6.56	7.36	7.42	7.78	7.86	8.34	8.13	9.52	8.86	12.28	10.56

(with or without oxygen enrichment) are such as to make the whole project economically questionable. Also, a technical problem having to do with the roaster heat balance and removal of excess heat for these lower-grade feeds has not been considered up to this point.

In the roasting or oxidation of any particular pyrite-coal feed material a certain amount of heat is generated over and above that required to maintain the roasting reaction at the desired temperature level. With oxygen-enriched air, the volume of feed-oxidation-product gas is less than where only air is used. As a result less heat is removed as sensible heat in the product gas and therefore more excess heat must be removed by steam-generating bed coils or by water injection when employing oxygen enrichment. As the grade of pyrite feed decreases (less pyrite, more coal) this generation of excess heat becomes more and more of a problem. Somewhere down the line of decreasing feed grade it becomes no longer possible to physically place sufficient heat-absorbing steam-generating coil surface in the fluid bed; it becomes necessary to materially increase the number of lines of roasters required for a given production capacity. This, of course, increases both capital costs and operating costs. For Plant Type II, which uses water or weak acid for removal of excess heat and for control of roasting temperature, the amount of additional water or weak acid required for a plant employing oxygen enrichment materially increases the roaster exit-gas volume. This in turn makes for larger and more expensive gas cooling and cleaning equipment. For these technical reasons the possible use of oxygen, even for large tonnages, is not a solution for reducing processing costs.

The use of oxygen instead of secondary air in the acid plant, to supply the oxygen required for SO_2 oxidation, might be considered as an alternative to using oxygen-enriched air for the pyrite roaster. This approach would have the following effect upon the process: (1) the total oxygen requirement would be less but this oxygen, because of the lower demand, would be more expensive per pound; (2) the pyrite roasting plant would not benefit by reduced equipment size, and (3) the acid plant would benefit by the use of oxygen in place of secondary air from the standpoint of the acid-plant water balance and from the standpoint of the heat balance.

Without going into detailed process calculations or plant cost data, we believe it quite likely that the use of oxygen in place of secondary air would show less economic benefit than if oxygen were used to enrich the air to the pyrite roasters.

A more practical approach might be to consider the possibility of adding both elemental sulfur and oxygen to the roaster as a means of decreasing the processing costs. This would involve a detailed technical and economic study to determine the possible merits for this approach.